GLOBAL CHANGE NEWSLETTER

www.igbp.kva.se

No. 59, September, 2004

The Global Change NewsLetter is the quarterly newsletter of the International Geosphere-Biosphere Programme (IGBP).

IGBP is a programme of global change research, sponsored by the International Council for Science.

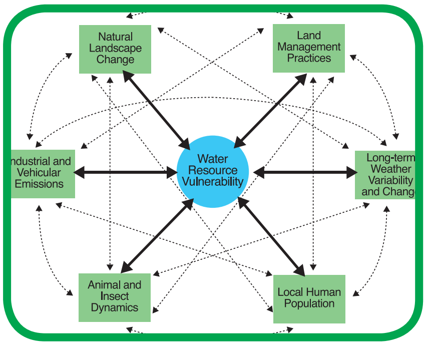
Compliant with Nordic Ecolabelling criteria.

New Executive Director for IGBP

In this issue we introduce Kevin Noone, the new Executive Director for IGBP. Read Kevin's perspective on IGBP (*Guest Editorial on Page 2*), learn about the science Kevin and colleagues have been undertaking (*Science Feature Page 6*), and find out more about Kevin's background (*New Roles and Faces on Page 22*).

Pages 2, 6 and 22

Discussion Forum: How Good are Climate Projections?



In the Discussion Forum Roger Pielke Sr describes the limitations of the scenario approach to planning for the future in the context of climate change. He contends that current climate models do not even include all the important forcings and feedbacks, and hence are at best a partial and uncertain basis for predicting future climate. He outlines the merits of a vulnerability approach to planning that considers a wider spectrum of risks, and considers relative importance of climate change and population growth on key resources.

Page 16

Oceanic Carbon Sinks

The global oceans are a major carbon sink. Read about the importance of shelf sea pumping for ocean carbon storage and what might mean for the global oceanic carbon uptake (Page 3). The high Arctic is considered as a potential "canary" for global warming, and hence the carbon budget of this region of great interest. Research associated with the Danish IGBP National Committee has been quantifying the carbon budget of this sensitive region including the oceanic carbon sink (Page 11). Our ability to artificially increase carbon storage in the oceans is considered in the Discussion Forum where the potential usefulness of a range of "macro-engineering" options for management and mitigation of climate change are considered (Page 20).

Pages 3, 11 and 20

IGBP at EuroScience

The first Euroscience Open Forum was held in Stockholm, Sweden during August 2004. It was the first pan-European scientific meeting staged to provide an interdisciplinary forum for open dialogue, debate and discussion on science and technology.

Page 27

Guest Editorial

So, what is IGBP anyway?

In this Editorial I try to convey my impressions and feelings about taking over at the helm of IGBP as Executive Director. First, there is a tremendous sense of excitement. Excitement about the science to be done in the field that IGBP has helped to form – Earth System Science. Excitement about the challenge of ensuring that a large group of gifted scientists across the world and across many different disciplines work together to expand and integrate our knowledge of how the Earth System works, and how we humans are an integral part of the system. Excitement at the opportunity to broaden my own horizons; to learn about areas and issues well beyond my current scientific interests, and to learn from the very best.

I come to IGBP as an outsider – although I've been unofficially involved with the IGAC and iLEAPS projects. I'd like to think that this relative inexperience with IGBP will allow me to approach the second phase of IGBP with fresh eyes and ears. My background for the past 15 years has been in academia – research and education, thinking about aerosols, clouds, climate and health issues. I'm fortunate to have worked in stimulating and diverse environments including the Department of Meteorology at Stockholm University, Sweden, and the Center for Atmospheric Chemistry Studies at the Graduate School of Oceanography, University of Rhode Island. This background has given me a good feel for the challenges, frustrations and joys of interdisciplinary research, and several useful perspectives as I start my journey with IGBP.

First and foremost, science must remain the heart and soul of IGBP. Not just good science, but world-class science. The issues of global change are so profound, and so important to society, that we cannot afford to settle for just good science.

We must be willing to work in an interdisciplinary fashion. I've encountered much debate – at times fairly heated – to the effect that interdisciplinary science is too "touchy-feely" to be considered real science. While I don't share that opinion, I do feel that it contains a kernel of truth: interdisciplinarity requires a firm basis in some discipline. A focused, reductionist approach to some questions is a necessary component in understanding global change, but is insufficient to fully understand the Earth System. We need both integrative and disciplinary approaches to make real progress. Unfortunately, our educational systems and research infrastructure aren't well designed to promote interdisciplinary work. There are relatively few university programs world-wide that train scientists for interdisciplinary research, and the rewards for doing so within the existing systems are often few and far between. It is often still difficult to convince both colleagues and funding agencies that scientific integration requires more than collating results from a number of independent projects, and must be planned and resourced from the beginning as a scientific activity in its own right.

Recently many of my scientific colleagues (not to mention my non-scientific friends) have asked "So, what is IGBP anyway?" We need to find new ways of communicating what we do – not only among ourselves, but also to other audiences including politicians, agency representatives, educators, the media, and the general public. We need to communicate both scientific findings as well as the excitement we feel about our work. The next generation of Earth System scientists cannot be taken for granted – we must engage and enthuse them now. Continued financial support can't be taken for granted either, but will ultimately depend on the general public's belief that what we do is important. It will not be considered important if politicians and the public do not know what we do.

Finally, research within IGBP is done by individuals – scientists from around the world who have voluntarily come together to collectively pursue common goals. The structure of IGBP must help us reach those goals – it must be an aid, not an imposition. IGBP is, in the end, what we choose it to be. These sentiments are not new – IGBP was founded on them, and my restatement of them is simply a reaffirmation and a commitment to the course set by my predecessors. I'm absolutely delighted to join the IGBP community, to learn about the myriad activities, to exchange ideas and opinions, and to contribute to learning more about the Earth System. It's going to be a great ride.

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Contents

Ocean CO_2 Storage from Shelf Sea Pumping

H. Thomas, Y. Bozec, K. Elkalay and H.J.W. de Baar

Coastal and marginal seas reveal strong biological activity, in part triggered by terrestrial and human impacts, and they play an important role in the global carbon cycle by linking the terrestrial, oceanic and atmospheric carbon reservoirs [1]. The high biological activity causes high CO_2 fluxes between the coastal and marginal seas, the atmosphere and the adjacent open oceans, respectively. Considering the surface area, coastal seas thus might have a disproportionately high contribution to the open ocean storage of CO_2 via a mechanism called the "continental shelf pump" [2]. During recent years detailed field studies have been initiated in a few areas including the East China Sea, the northwest European shelf, the Baltic Sea and the North Sea. However, there is only limited information available on these CO_2 fluxes at the global scale [3,4,5].

The North Sea, a sea of the northwest European shelf, is amongst the best-studied coastal areas in the world with respect to its physical, chemical and biological conditions, as it has been subject to detailed investigations for many years. A pioneering basin-wide study provided the first insights in the North Sea carbon cycle relying on a six-week field survey during late spring 1986 [6,7]. Further carbon cycle studies in the North Sea were confined to certain near-shore coastal areas such as the German Bight, the Wadden Sea or the Belgian coast [see 8]. In order to verify the continental shelf pump hypothesis for the North Sea, an intense field and modelling study was initiated by an international consortium from the Royal Netherlands Institute for Sea Research, The Netherlands, the University of Liege, Belgium, the Alfred-Wegener-Institute for Polar Research, Germany and the University of Hamburg, Germany. The field program spanned four consecutive seasons at high spatial resolution to comprehensively investigate the carbon cycle and its controlling processes. During each cruise, ninety-seven stations were sampled for carbon and related nutrient cycle parameters. The partial pressure of CO_2 (pCO_2) and hydrographic parameters were measured continuously in the surface waters [8,9,10].

The North Sea can be subdivided into two biogeochemical provinces: a shallower south-

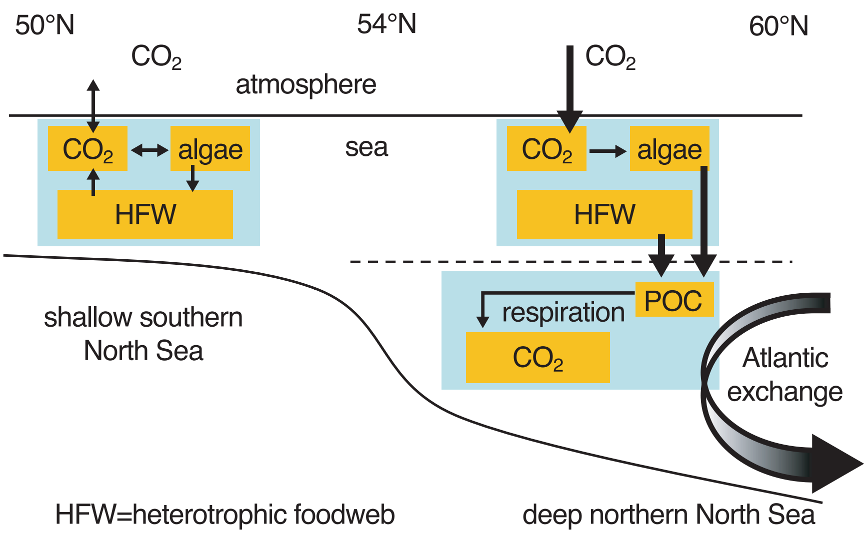

Figure 1. South-north section through the North Sea. In the shallower southern region production and respiration processes occur in the mixed layer, whereas in the northern region respiration processes mainly occur in the separated subsurface layer, which is subjected to exchange circulation with the North Atlantic Ocean. The dashed line indicates the thermocline, and the darkening of the arrow implies the increase of dissolved inorganic carbon in the North Atlantic Ocean water circulated through the North Sea [after 10].

Figure 2. Distribution of the CO_2 partial pressure difference (ΔpCO_2) during four consecutive seasons. The surface water data were recorded at one minute intervals and the atmospheric data at hourly intervals. The data are shown relative to the atmospheric pCO_2 observed during each cruise. Negative values denote under-saturation of the surface waters. The cruises [9] took place in August/September 2001 (summer), November 2001 (autumn), February/March 2002 (winter) and May 2002 (spring) on the research vessel RV Pelagia. The same colour scale has been applied to all plots [after 10].

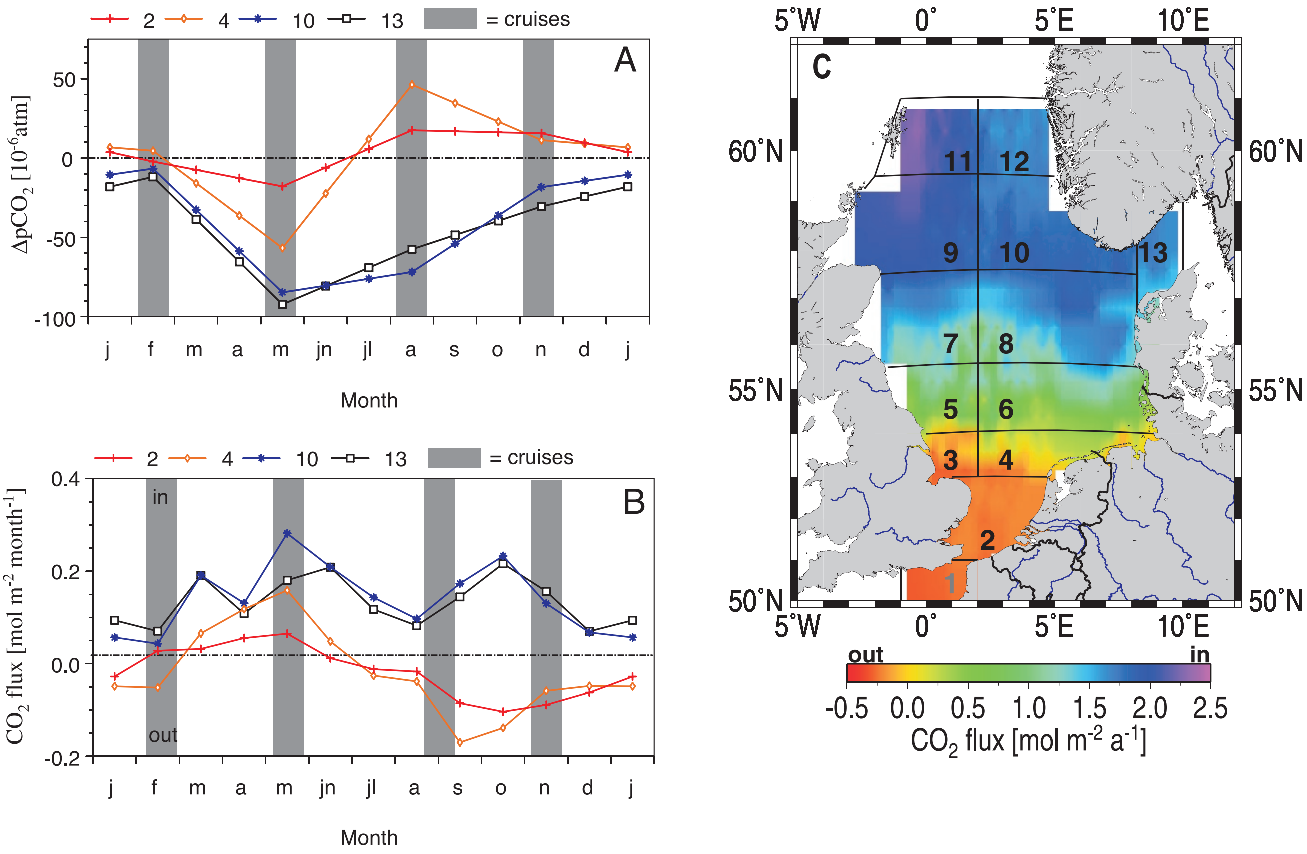

Figure 3. Annual cycles of air-sea partial CO_2 pressure differences (A) and calculated CO_2 flux (B) for selected areas (grid boxes in C) in the North Sea, with shading indicating periods of observation. The spatial pattern of the annual air-sea CO_2 fluxes across the North Sea is shown in C. The numbers given on the top of (A) and (B) relate to the grid boxes indicated in (C) [after 10].

ern part, in which the water column is mixed throughout the whole year, and a deeper northern part that thermally stratifies during the warmer period of the year. The bottom topography thus exerts a major control on the biogeochemical cycles, with strong impact on the carbon export from the North Sea to the North Atlantic Ocean via the continental shelf pump. Carbon export occurs because thermal stratification of the northern section allows particulate organic carbon from algal production to move from the warmer surface waters down into the cooler sub-surface layer. Since the thermocline prevents the mixing of surface and subsurface waters, most of the CO_2 that is subsequently released into the subsurface layer from heterotrophic respiration of this particulate organic carbon, is transported northwards to the North Atlantic Ocean by sub-surface ocean circulation (Figure 1). This exported carbon is replenished from the atmosphere – constituting the "continental shelf pump". The shallower

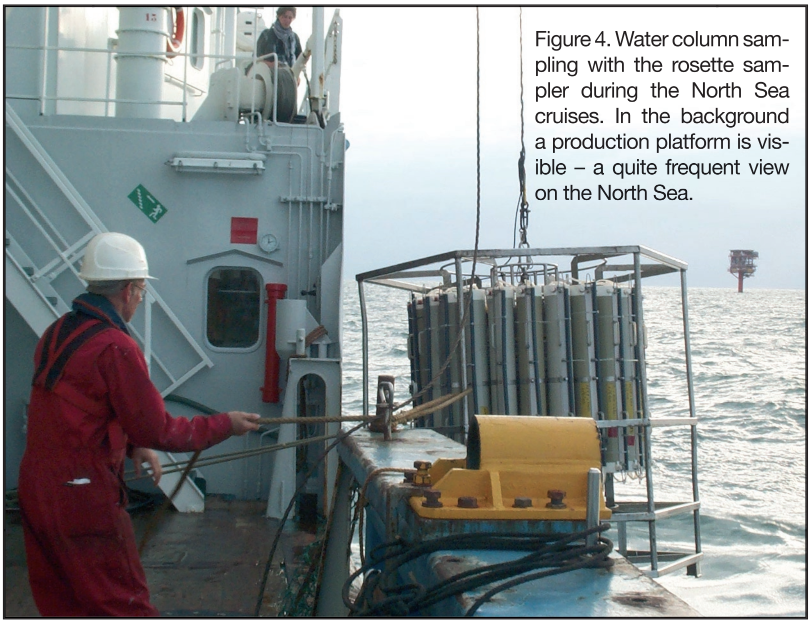

Figure 4. Water column sampling with the rosette sampler during the North Sea cruises. In the background a production platform is visible – a quite frequent view on the North Sea.

non-stratified southern section does not contribute to this carbon transport, since both algal production and heterotrophic respiration occur within the year-round mixed water column, thus preventing significant exports. The CO_2 air-sea fluxes are neutral or weak.

This process was verified by the continuous measurements of the partial pressure difference between atmosphere and surface water (ΔpCO_2), which governs the CO_2 air-sea flux. It shows a strong seasonal and spatial variability, the latter one reflecting the two biogeochemical provinces. During winter (Figure 2a) almost no difference between the atmospheric and the surface water pCO_2 can be observed. CO_2 under- or super-saturation has only been recorded locally. With the onset of the spring bloom the entire North Sea becomes strongly under-saturated (Figure 2b) – even in the shallow, southern unstratified region. During summer the surface water ΔpCO_2 distribution (Figure 2c) shows clear differences between the two biogeochemical provinces. The stratified, northern region exhibits a strong CO_2 under-saturation up to -150 ppm ΔpCO_2, whereas the shallower unstratified southern region is strongly supersaturated with ΔpCO_2 values up to approximately 100 ppm. In the southern region nutrients become exhausted in the summer, so primary production slows down and respiratory processes dominate the carbon cycling generating the observed CO_2 super-saturation. In the northern region CO_2 further accumulates in the subsurface layer because of organic matter respiration (Figure 1), thereby preventing the increase of the pCO_2 in the surface layer. In the autumn (Figure 2d), biological activity decreases and the northern mixed layer deepens, allowing the ΔpCO_2 in both regions to begin to equilibrate towards the winter state.

The seasonal variations of partial pressure differences, interpolated for 13 sectors of the North Sea, coupled with 6-hourly wind field data [11] enable the seasonal variations in CO_2 flux and the spatial patterns in annual CO_2 flux to be calculated (Figure 3). According to the seasonal variations of the ΔpCO_2, the CO_2 fluxes reveal different patterns in the southern and northern region (Figure 3a). The southern part shows the seasonal pattern of low latitude regimes, characterised by a strong temperature and only a weak biological control. Because pCO_2 increases with temperature, the southern pCO_2 maximum occurs in summer and the minimum in winter; despite the fact that the southern region has some of the highest marine biological activity in the world.

As described above however, the coexistence of production and respiration in the same layer prevents strong net biological effects on air-sea CO_2 fluxes. In contrast, the northern region has a typical high latitude pattern of CO_2 fluxes, with pCO_2 minima occurring in spring and summer due to biological CO_2 drawdown, and maxims occurring in winter due to respiratory processes. This sub-system is thus strongly controlled by biological activity causing a net CO_2 drawdown from the surface water, with ultimate export to the North Atlantic Ocean.

The annual integration of the CO_2 fluxes reveals that much of the North Sea acts as a year-round CO_2 sink. The only source – though still minor – is from the southern areas during late summer. The largest fluxes occur firstly in May during spring algal blooms, and secondly in October, when storms force CO_2 uptake. The northern part (north of 54°N) of the North Sea absorbs 1.7 mol CO_2 m^{-2} yr^{-1} from the atmosphere, whereas the southern region releases 0.2 mol CO_2 m^{-2} yr^{-1}. The overall CO_2 uptake by the North Sea amounts to 1.3 mol CO_2 m^{-2} yr^{-1}, which is almost entirely exported to the North Atlantic Ocean, since less than 1% of the algal carbon that is produced is sequestered in the North Sea sediments [12]. Extrapolating the North Sea's CO_2 uptake across coastal areas of the global ocean (7%), would suggest coastal seas absorb approximately 20% of the global oceanic uptake of

Acknowledgements

The excellent co-operation of the captains, the crews of RV Pelagia and the scientific staff is gratefully acknowledged. This study has been encouraged by and contributes to the LOICZ project of IGBP and IHDP. It was primarily funded by the Research Council for Earth and Life Sciences (ALW) of the Netherlands Organisation for Scientific Research (NWO) and the Dutch-German bilateral co-operation NEBROC.

anthropogenic CO_2. Coastal seas appear to substantially enhance the open ocean sequestration of CO_2. Future research will help to better quantify the role of coastal seas in the global carbon cycle.

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References

1. Gattuso J-P, Frankignoulle M and Wollast R. (1998) Carbon and carbonate metabolism in coastal aquatic ecosystems. Annual Reviews of Ecological Systems, 29, 405-434.
2. Tsunogai S, Watanabe S and Sato T. (1999) Is there a "continental shelf pump" for the absorption of atmospheric CO_2? Tellus 51B, 701-712.
3. Chen C-T A, Liu K-K and MacDonald R. (2003) Continental margin exchanges. In: Fasham MJR (Ed.) Ocean Biogeochemistry: A JGOFS Synthesis, Springer, 53-97.
4. Liu K-K et al. (2000) Exploring continental margin carbon fluxes on a global scale. EOS 81, 641-64.
5. Andersson AJ and Mackenzie FT. (2004) Shallow-water oceans: a source or sink of atmospheric CO_2. Frontiers in Ecology and the Environment 2, 348-353.
6. Pegler K and Kempe S. (1988) The carbonate system of the North Sea: determination of alkalinity and TCO_2 and calculation of PCO_2 and SIcal (spring 1986). Mitteilungen des Geologisch-Paläontologischen Institutes der Universität Hamburg 65, 35-87.
7. Kempe S and Pegler K. (1991) Sinks and sources of CO_2 in coastal seas: the North Sea. Tellus 43B, 224-235.
8. Bozec Y et al. (2004) The continental shelf pump in the North Sea – evidence from summer observations. Marine Chemistry, in press.
9. Thomas H. (2002) Shipboard report of the RV Pelagia cruises 64PE184, 64PE187, 64PE190 and 64PE195 (Royal Netherlands Institute for Sea Research, Texel, NL.
10. Thomas H et al. (2004) Enhanced open ocean storage of CO_2 from shelf sea pumping. Science 304, 1005-1008.
11. ECMWF. (2002). European Centre for Medium Range Weather Forecast, 40-year reanalysis of wind data ERA 40. http://www.ecmwf.int.
12. De Haas H, Van Weering TCE and De Stigter H. (2002) Organic carbon in shelf seas: sinks or sources, processes and products. Continental Shelf Research 22, 691-717.

Aerosols and Their Role in the Earth's Energy Balance

K.J.Noone, A.Targino, G.Olivares, P.Glantz and J.Jansson

Aerosols directly influence climate by scattering or absorbing incoming solar radiation, and indirectly influence climate by acting as nuclei on which clouds can form. Jointly these effects represent the largest uncertainty in our current understanding of the Earth's energy balance. Improved understanding is therefore needed of both the aerosol-cloud interactions that determine the optical properties of clouds and affect precipitation, and of the processes that determine the amounts and optical properties of atmospheric aerosols themselves. Measurements of the extent of anthropogenic influence on aerosol and cloud properties at the global scale are also important. The best way to develop the necessary process understanding is using a combination of field and laboratory measurements and model investigations. Global scale measurements are best obtained using satellite-based observing systems, but satellite data, however valuable and necessary, cannot replace *in situ* process studies for understanding how aerosols affect climate.

In this article we summarise some of the recent and current research activities in the Atmospheric Physics Division, Department of Meteorology, Stockholm University. This research has taken an integrated approach to learning about the atmosphere by combining *in situ* measurements of aerosols, clouds and trace species, remote sensing studies of these quantities, and process-scale model investigations. A process-based approach has been adopted to the determination of how anthropogenic emissions of aerosols and gases influence cloud properties (both microphysical and chemical), and how aerosols and clouds affect the radiative balance of the Earth. Process information is then combined with satellite measurements to determine the nature and extent of the anthropogenic modification of the natural background aerosol and cloud fields, and detailed microphysical-chemical models are linked with field observations to explore and understand the processes behind trace gas-aerosol-cloud-climate interactions.

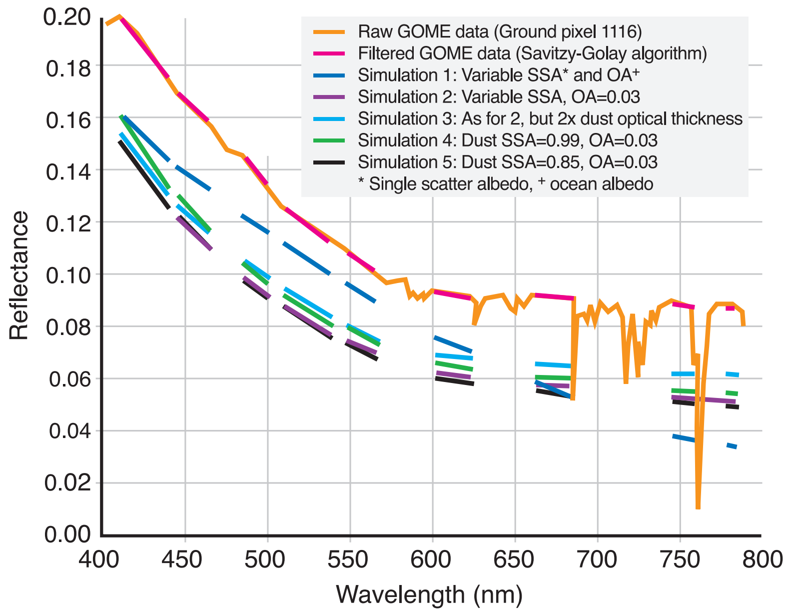

Figure 1. Reflectance vs. wavelength calculations for cloud-free pixels. The observed spectrum is at the top, with the calculated spectra below. None of the calculated spectra match the observed reflectance values.

Direct Radiative Effects of Aerosols

Aerosol properties are variable in the atmosphere. The aerosol mass field varies significantly on horizontal scales as small as 10-100 km, and can also vary considerably on vertical scales – even in the "well-mixed" troposphere. Satellite observations are often column measurements; for example, the amount of sunlight scattered upwards into the viewing geometry of a satellite integrated over the atmospheric column. Making good use of such measurements requires understanding how the spatial heterogeneity of the aerosol field affects the satellite retrieval of the property in question.

The RS "GOME Aerosol" project supported by the Swedish Space Board sought to combine the then most extensive *in situ* dataset of marine aerosol optics, microphysics and chemistry (ACE-2, [1-4]) with retrievals of aerosol optical depth from the GOME satellite. It sought to do so using a retrieval methodology that would take advantage of GOME's high spectral resolution and polarization information in the UV/VIS wavelengths to improve retrievals of aerosol properties, especially over land areas. The approach involved using the detailed measurements of aerosol properties made aboard the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) Pelican aircraft during ACE-2 to constrain aerosol retrievals for the same time and area from GOME.

Using ACE-2 measurements together with a forward radiative transfer model developed for GOME, the radiance spectrum that the satellite "should" have observed in the most cloud-free pixels in an image was calculated. Comparisons of the observed spectrum with calculated spectra using several different ocean surface albedo, aerosol single scatter albedo and cloud cover assumptions (Figure 1) show that cloud "contamination" is a major problem in using GOME data to retrieve aerosol properties. While pixels can be found in which the calculated and observed spectra agree very well, the large footprint of GOME severely limits its usefulness for aerosol studies, despite the high spectral resolution of the satellite radiometers.

This result, while a negative one, is useful in the sense that it illustrates the limitations of the GOME platform for aerosol retrieval, and directs attention towards other satellite platforms (e.g. SeaWIFS, Envisat, the A-Train satellites) for future aerosol and cloud studies.

Aerosol/Cloud Interactions and Organic Cloud Droplet Nuclei

Every cloud droplet starts its life as an aerosol particle. Understanding natural clouds, and how anthropogenic pollution affects cloud formation and development, requires understanding the processes that determine what fraction of the available aerosols actually form cloud droplets, and how this fraction is influenced by particle microphysics and chemistry.

To tackle these issues a sampling system was developed that separates cloud droplets from the air and surrounding interstitial aerosol particles, samples and evaporates the droplets, and determines the properties of the aerosols on which the droplets formed (the droplet *residual* aerosol particles). A major outstanding question after initial investigations [see 5-9] was the extent to which particle chemistry – particularly the chemistry of organic compounds – influence cloud droplet formation.

Figure 2. Interior of Mt. Åreskutan laboratory during set-up. The aerosol mass spectrometer from the University of Mainz is to the right.

A field experiment conducted in July 2003 at Mt. Åreskutan in central Sweden investigated the efficiency with which particles – particularly those containing organic species – form cloud droplets. A land-based Counterflow Virtual Impactor (CVI) system was used to sample cloud droplets, and a radial impactor was used to sample interstitial aerosol particles. Attached to both systems was instrumentation to determine the concentration, size, optical properties (scattering and absorption coefficients) and chemical composition of the residual and interstitial aerosol. An aerosol mass spectrometer was used to determine the size-resolved chemical composition of the residual and out-of-cloud aerosol (Figure 2).

Preliminary analyses revealed that organic compounds accounted for up to 60% of the aerosol mass, both in clean and polluted air. Particles smaller than 0.2 μm were a surprisingly large fraction of the cloud droplet residuals. During overnight drizzle the residual aerosol distribution mode decreased to well below 0.1 μm, but increased again in the morning when the drizzle stopped. The drizzle appeared to have played an important role in modulating the concentration of accumulation-mode particles during this period.

Sub-visible Cirrus Clouds and Clouds in the Tropopause Region

Cirrus clouds can act to either cool or warm the planet, depending on their optical thickness. Previous investigations (measurement campaigns and model simulations) into cirrus clouds have focused on understanding the mechanisms by which large concentrations of small ice crystals can be produced [7, 10-12]. These small crystals are important in determining the optical characteristics of cirrus clouds, which in turn determine how the clouds affect radiation transfer through them. Measurements have indicated that sub-micron aerosols control the number population of these small crystals, and that the relationship between residual particle size and cloud droplet size commonly observed in warm clouds does not hold for cirrus clouds. Consequently, understanding what controls the radiative properties of cirrus clouds requires an understand-

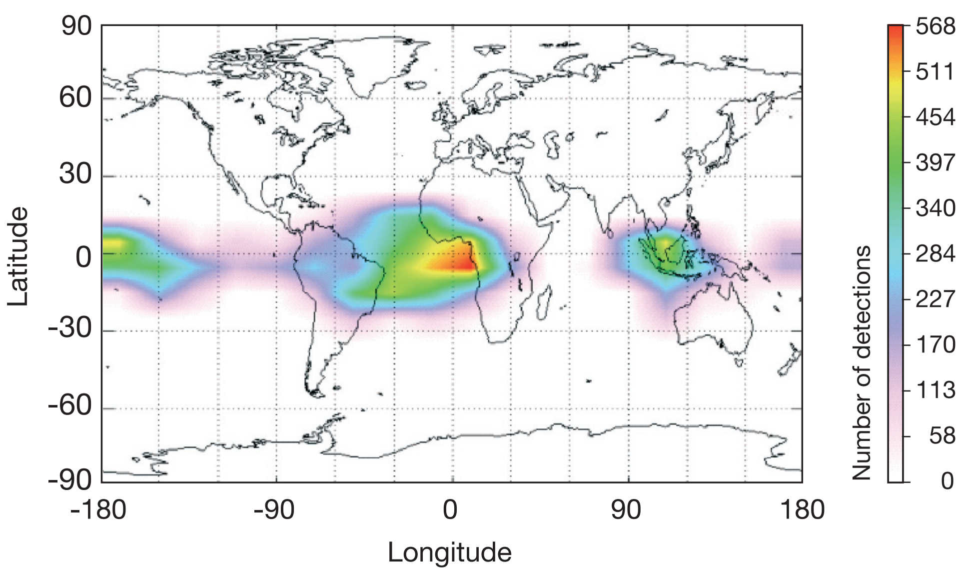

Figure 3. Occurrence of sub-visible cirrus clouds in the tropics during April, 2002. (Source: A. Bourassa, D. Degenstein, N. Lloyd and E. Llewellyn, University of Saskatchewan).

ing of what aerosol controls the number population of small crystals.

Optically thin cirrus clouds (sub-visible cirrus) are of particular interest because of their potential influence on the Earth's radiative balance. The few measurements that have been made in these clouds indicate that the crystals are typically small – under 20 µm [13] or even 10 µm or less [14]. Recent research has measured the concentration, condensed water content and nitric acid concentration of crystals in clouds in the tropical tropopause region [15,16]. Current work is using the Odin and SeaWIFS satellites to investigate the occurrence and properties of sub-visible clouds, including sub-visible cirrus clouds near the tropopause (e.g. Figure 3). An advantage of the limb scanning observational approach used by Odin is that information about the vertical distribution of these clouds is available (at least above about 7-8 km). To date, all of the clouds examined have been at or below the thermal tropopause height. Future investigations will examine whether the spatial distribution of the clouds is determined by purely dynamical driving forces, or whether there is spatial co-variation between cloud fields and aerosol fields.

Summary

This summary of aerosol and aerosol-cloud interaction investigations highlights the importance of an interdisciplinary and international approach to studies of the Earth's atmosphere, an approach which IGBP aims to facilitate. The studies summarised herein all complement and relate directly to the work of the IGBP core projects IGAC, SOLAS and iLEAPS, although only the ACE-2 project was undertaken under the auspices of IGBP.

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Acknowledgements

The authors acknowledge the contributions from several collaborators to the work described in this article, including: on the aerosol-cloud interactions studies, Lynn Russell (Scripps Institute of Oceanography), John Ogren (NOAA), David Covert (University of Washington), and Stephan Borrmann, Frank Drewnick, Johannes Schneider, Silke Henseler, Nina Hock, Silke Weimer (University of Mainz); on the sub-visible cirrus studies, Adam Bourassa, Douglas Degenstein and Edward Llewellyn (University of Saskatchewan).

References

1. Collins DR et al. (2000) *In-situ* aerosol size distributions and clear column radiative closure during ACE-2. Tellus 52B, 498-525.
2. Gassó S et al. (2000) Influence of humidity on the aerosol scattering coefficient and its effect on the up-welling radiance during ACE2. Tellus 52B (2), 546-567.
3. Öström E and Noone KJ. (2000) Vertical profiles of aerosol scattering and absorption measured *in situ* during the North Atlantic Aerosol Characterization Experiment (ACE-2). Tellus Series B-Chemical and Physical Meteorology 52(2), 526-545.
4. Schmid B et al. (2000) Clear-sky closure studies of lower tropospheric aerosol and water vapour during ACE-2 using airborne sunphotometer, airborne *in-situ*, space-borne, and ground-based measurements, Tellus Series B-Chemical and Physical Meteorology 52(2), 568-593.
5. Hallberg A, Noone KJ and Ogren JA. (1998) Aerosol particles and clouds: which particles form cloud droplets? Tellus 50B, 59-75.
6. Hallberg A et al. (1994) Phase partitioning of aerosol particles in clouds at Kleiner Feldberg. Journal of Atmospheric Chemistry 19, 107-127.
7. Lin H et al. (1998). Small ice crystals in cirrus clouds: a model study and comparison with *in-situ* observations. Journal of the Atmospheric Science 55(11), 1928-1939.
8. Noone KJ et al. (1992) Changes in aerosol size and phase distributions due to physical and chemical processes in Fog. Tellus 44B(5), 489-504.
9. Noone KJ et al. (2000) A case study of ships forming and not forming tracks in moderately polluted clouds. Journal of the Atmospheric Sciences 57(16), 2729-2747.
10. Lin H et al. (1998) Dynamical influences on cirrus cloud formation process. Journal of the Atmospheric Sciences 55(11), 1940-1949.
11. Noone KB et al. (1993) *In-situ* observations of cirrus cloud microphysical properties using the counterflow virtual impactor. Journal of Atmospheric and Oceanic Technology 10, 294-303.
12. Ström J et al. (1994) Small crystals in cirriform clouds: a case study of residue size distribution, cloud water content and related cloud properties. Journal of Atmospheric Research 32(1-4), 125-141.
13. McFarquhar GM et al. (2000) Thin and sub-visual tropopause tropical cirrus: observations and radiative impacts. Journal of the Atmospheric Sciences 57(12), 1841-1853.
14. Thomas A et al. (2002) *In-situ* measurements of background aerosol and subvisible cirrus in the tropical tropopause region. Journal of Geophysical Research 107(D24), 4763.
15. Luo BP et al. (2003) Ultra-thin tropical tropopause clouds (UTTCs): II. Stabilization mechanisms. Atmospheric Chemistry and Physics Discussions 3, 1579-1597.
16. Peter T et al. (2003) Ultra-thin tropical tropopause clouds (UTTCs): I. Cloud morphology and occurrence. Atmospheric Chemistry and Physics Discussions 3, 1557-1578.

High Artic Carbon Sink Identification – A Systems Approach

H.Soegaard, L.Sørensen, S.Rysgaard, L.Grøndahl, B.Elberling, T.Friborg, S.E.Larsen and J.Bendtsen

The carbon budget of the High Arctic is one of the best indicators of the health of our planet. Over the last two decades climate models [e.g.1] have predicted that warming caused by elevated atmospheric CO_2 would be strongest and fastest in the Arctic. The most recent regional climate predictions are for an average Artic temperature increase of 1.7°C by the middle of this century, and location-specific temperature increases of 1 to 4°C [2]. Because of strong feedback mechanisms in the Arctic even moderate temperature changes may be amplified and result in large environmental responses.

In northern Scandinavia where annual average temperatures are around 0°C, recent warming has rapidly reduced the areas with permafrost [3] which could cause large increases in methane emission. Along the coast of northeast Greenland the lower average annual temperature (-10°C) means permafrost is less sensitive to warming. Here however, a clear response is seen in the decreasing extent of sea-ice. The effect on the terrestrial carbon balance is, however, not straightforward. On the one hand decreasing sea-ice leads to denser snow cover and shorter growing seasons with less carbon uptake, but on the other hand, actual CO_2 flux measurements show that carbon uptake in recent years has increased with the rising summer temperatures. Due to the multiple feedbacks, a systems approach, rather than a single process-study, is appropriate for determination of the High Arctic carbon budget.
In this article a summary of this approach is presented based on a number of Danish IGBP activities, and using the comprehensive data set from the Zackenberg research station (74.5°N, 20.5°W) and from the surrounding land and sea areas (Figure 1).

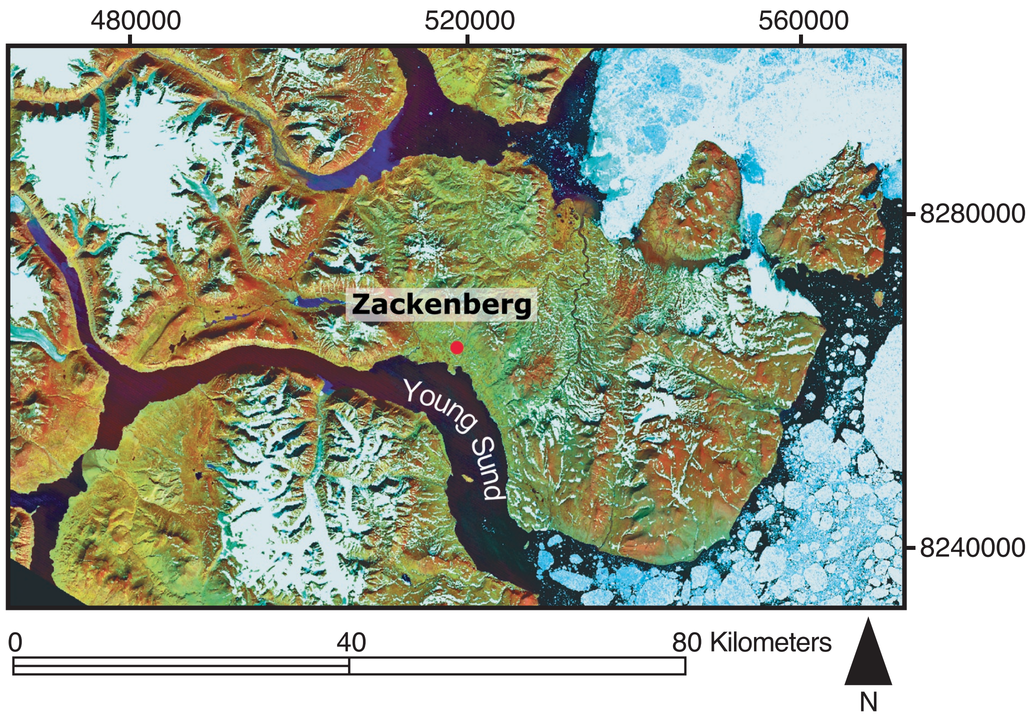

Figure 1. Landsat images of the Zackenberg study area. The red spot indicates the site of discharge and carbon measurements.

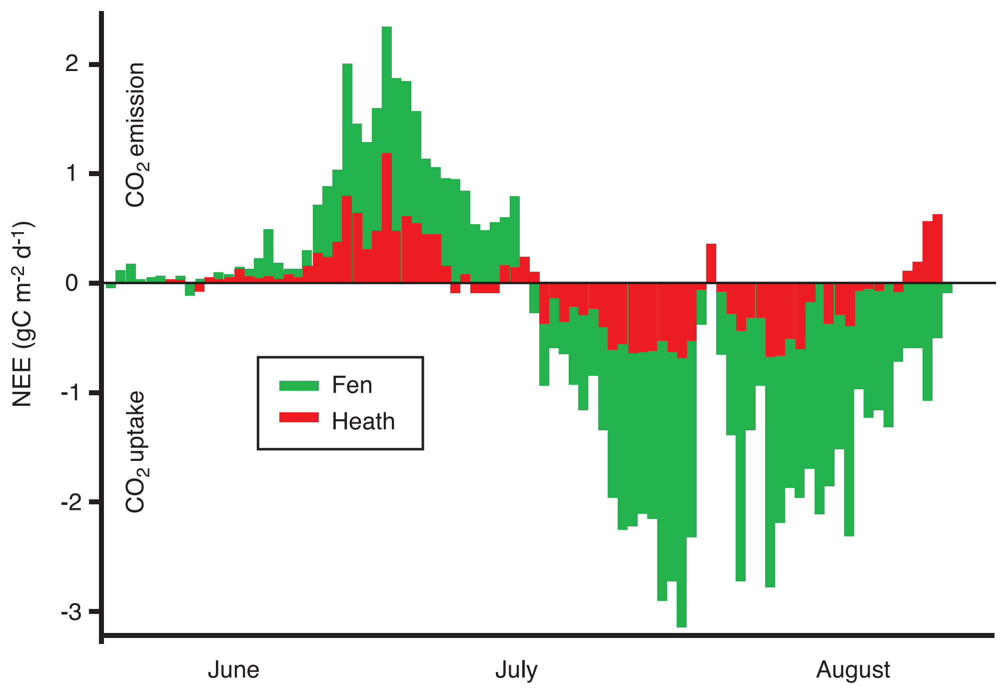

Figure 2. Temporal variation in Net Ecosystem Exchange (NEE) for two vegetation types (sedge-dominated fen and dwarf-shrub heath) for a selected year (1997).

Terrestrial Carbon Fluxes

During the summer the terrestrial ecosystem constitutes the upper step of the carbon cascade where CO_2 fixation takes place nearly 24 hours a day due to the midnight sun. Summer CO_2 fluxes have been recorded for two contrasting vegetation types: a sedge-dominated fen (1996-1999) [4] and dwarf shrub heath (1997, 2000-2004). The temporal variation in CO_2 exchange (Figure 2) shows CO_2 emission in late June when the snow disappears from both vegetation types. CO_2 emission from the fen however, is greater due to the higher soil carbon content. In July, when the leaves develop, the ecosystem is rapidly transformed into a net carbon sink due to the relatively high photosynthetic rates during the peak growing season. From early August, lower sun angles and leaf senescence cause carbon sequestration to diminish, and whilst the fen continues as a net carbon sink until the end of August, the heath becomes a net carbon source from as early as mid-August. Combining these areal carbon sequestration rates with the areal extent of the two vegetation types in the study area (Figure 1) provides an estimate of the terrestrial carbon balance for the summer (10 g m^{-2} per season) [4]. Applying a soil respiration model allows estimation of the winter carbon budget, and summing the winter and summer budgets provides an estimate of the annual budget (Table 1). This budget includes the carbon emitted as methane (15 g m^{-2} yr^{-1}) from the fens covering 2-3% of the area.

Carbon Transport Through the Fluvial System

Carbon is transported through the High Arctic rivers during an intensive 3-4 month period (June-September). The peak discharge occurs in June-July associated with snowmelt. Carbon is transported to coastal waters in both dissolved forms and particulate forms (particulate organic carbon – POC). The dissolved carbon comes partly from the decomposition of soil organic matter and partly from the dissolution of soil carbonate minerals. Over the summer the average carbon concentration is usually relatively constant at around 4-5 mg L^{-1}, although the concentration can as much as double in connection with landslides. POC transport is equivalent to about one quarter of the dissolved carbon transport,

Component	Type	Ice	Area	Atmospheric Flux (A)		Fluvial Transport (F)		Lateral Marine Transport		Net Flux	Net change in storage
		%	km^2	$t\ yr^{-1}$	$g\ m^{-2}\ yr^{-1}$	$t\ yr^{-1}$	$g\ m^{-2}\ yr^{-1}$	$t\ yr^{-1}$	$g\ m^{-2}\ yr^{-1}$	$g\ m^{-2}\ yr^{-1}$	$g\ m^{-2}\ yr^{-1}$
Zack Basin	Terrestrial-Fluvial		512	**-1,200**	**-2.3**	**-1,400**	**-2.7**	0.0	0.0	**-0.4**	not available
Young Basin	Terrestrial-Fluvial		3,100	-4,700	*-1.5*	4,600	-1.5	0.0	0.0	0.0	not available
Young Sund	Coastal	80	396	-1,560	**-3.9**	-4,600	-12	**-2,800**	**-7.1**	**-23**	**-19**
Greenland Sea	Marine	20	300,000	$-13x10^6$	**-42**	0.0	0.0			-42	**-2.0**

Table 1: Carbon exchanges by study area component. Values given in bold are based on in-situ measurements and values given in italics are found by satellite based up-scaling. Downward directed fluxes are negative, upward fluxes are positive.

but it nearly doubles at the time of the maximal biological activity in early August. Based on four years (2000-2003) of summer measurements at Zackenberg the total (dissolved and suspended) fluvial carbon transport is estimated to be approximately 1,400 t. Distributing this amount equally over the upstream drainage basin (512 km^2) gives an estimated areal annual carbon flux of approximately 2.7 g m^{-2} which is nearly equal to the terrestrial carbon fixation (Table 1).

CO_2 fluxes over the Arctic Ocean

The open Arctic seas function as a year-round carbon sink pumping atmospheric CO_2 into the sea and thereby producing dissolved inorganic carbon (DIC). The uptake rate is largely controlled by the CO_2 difference across the air-sea interface (ΔCO_2), the presence of sea-ice and the atmospheric wind forcing of the surface waters. During winter an under saturation of CO_2 is maintained in the open sea because of the higher solubility of CO_2 at low temperatures and because the stronger winds enhance the transport of CO_2 across the sea surface. During summer the CO_2 difference is larger because micro-organisms transform DIC into organic compounds that sink deeper into the sea, however, the winds are calmer. Based on modelling [5] the carbon (as CO_2) flux from the atmosphere to the Arctic sea is assumed to be relatively constant with average monthly fluxes ranging from 2 to 6 g m^{-2}. These estimates are verified by recent observations collected during three research cruises in the North Atlantic and the Greenland Sea (Figure 3), which despite scatter due to differences in season and weather indicate that the largest ΔCO_2 is located in the Artic rather than in the North Atlantic. Assuming that the three sampling months (April, June, October; Figure 3) are representative of the annual range of conditions, the annual carbon uptake by the ice-free part of the Greenland Sea is 52 g m^{-2}, which is in accordance with Anderson et al. [5]. Because the sea ice puts an effective lid on the air-sea exchange, the actual uptake is assumed to be proportional

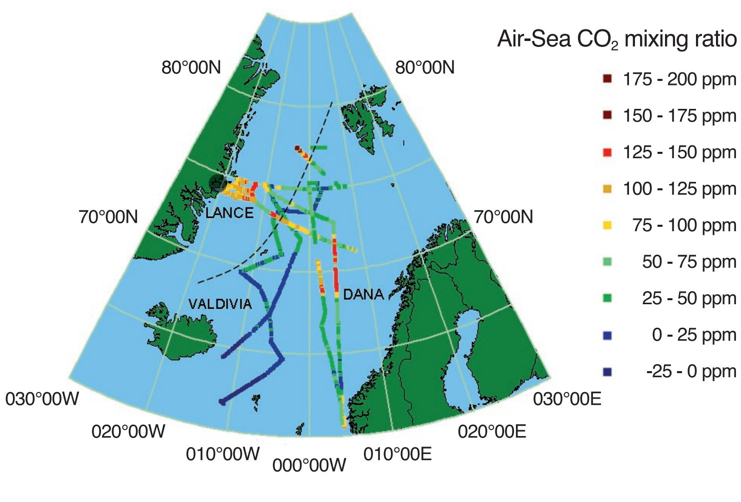

Figure 3. Air-sea mixing ratio measured during three different cruises in the northern north Atlantic: Valdivia (April 1999), Dana (June 1999), Lance (October 2003). The dashed line encircles the High Arctic observations.

with ice-free fraction of the sea which varies with the distance from the coast. In winter dense drifting ice is normally found up to a distance of >200 km from the coast whereas in late summer the sea ice becomes a narrower band (<100 km) with discontinuous ice. Long-term ice cover records shows a spatial variation from 80% in the inner fjords to 20% in the Greenland Sea [5] (Table 1).

Carbon deposition in the fjord system

The extensive 396 km2 Young Sund fjord system functions as the lowest step on the carbon cascade collecting fluvial carbon from a 3,100 km^2 drainage basin, marine carbon from the Greenland Sea and CO_2 from the atmosphere. By scaling the fluvial carbon measured at the Zackenberg site (1,400 t yr^{-1}) up to the whole Young Sund drainage basin suggests an export of 4,600 t yr^{-1}, which distributed over the entire drainage area gives an annual areal carbon export of 11.8 g m^{-2}. Hydrographic observations [6] give an estimate 35.1 t d^{-1} for the marine net carbon inflow from the Greenland Sea, which scaled to the area of the fjord corresponds to a net carbon input of 0.09 g m^{-2} d^{-1}, or 7.1 g m^{-2} for the summer. The atmosphere is the third carbon source. CO_2 gradient measurements across the sea-air interface suggest average atmospheric carbon fluxes (as CO_2) of 0.05 g m^{-2} d^{-1}. Based on an 80 day productive summer period this corresponds to an annual carbon flux of 3.9 g m^{-2}. Comparing the sum of the annual oceanic, the fluvial and atmospheric carbon contributions (23 g m^{-2}) to annual vertical carbon fluxes of 19 g m^{-2} measured at a depth of 66 m [7] the systems approach is again demonstrated to be effective in reducing the uncertainties in carbon budgets.

For the terrestrial-fluvial system there is reasonable balance between sources and sinks (deviation less than 20%), and for the coastal ecosystem the net carbon flux is very similar to sediment trap measurements that indicate accumulation in storage (two right-hand columns of Table 1). For the Greenland Sea however, there is a huge discrepancy between the net surface flux and measured sedimentation (net change in storage). This is largely because the carbon uptake by the surface waters (0-150 m) is mixed down to the deep layers and will remain isolated from the atmosphere for centuries. To balance this budget we must assume a lateral transport of 40 g m^{-2} yr^{-1}. An improved carbon budget would thus require detailed ocean modelling as well as data for historic climatic trends and wintertime processes.

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References

1. Maxwell B. (1992) Arctic Climate: Potential for Change Under Global Warming. In: Arctic Ecosystems in a Changing Climate: An Ecophysiological Perspective (Eds. Chapin III FS, Jefferies RL, Reynolds JF, Shaver GR and Svoboda J). Academic Press, pp11-34.
2. Callaghan TV et al. (2004) Environmental Changes in the North Atlantic Region: SCANNET as a collaborative approach for documenting, understanding and predicting changes. Ambio (in press).
3. Christensen TR et al. (2004) Thawing sub-arctic permafrost: Effects on vegetation and methane emissions. Geophysical Research Letters 31(4), L04501.
4. Soegaard H et al. (2000) Trace gas exchange in a high-arctic valley 3: Integration and scaling of CO2 fluxes from canopy to landscape using flux data, footprint modelling and remote sensing. Global Biochemical Cycles 14(3), 725-744.
5. Anderson LG et al. (2000) Annual carbon fluxes in the upper Greenland Sea based on measurements and a box-model approach. Tellus 52B, 1013-1024.
6. Rysgaard S et al. (2003) Physical conditions, carbon transport, and climate change impacts in a northeast Greenland fjord. Arctic Antarctic and Alpine Research 35(3), 301-312.
7. Rysgaard S et al. (in press). The MarinBasic program - monitoring program report 2002-2003. In: Zackenberg Ecological Research Operations, ZERO, Eds. Caning K and Rasch M. 8th Annual Report, 2003 Copenhagen. Danish Polar Center, Ministry of Science, Technology and Innovation.

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Discussion Forum

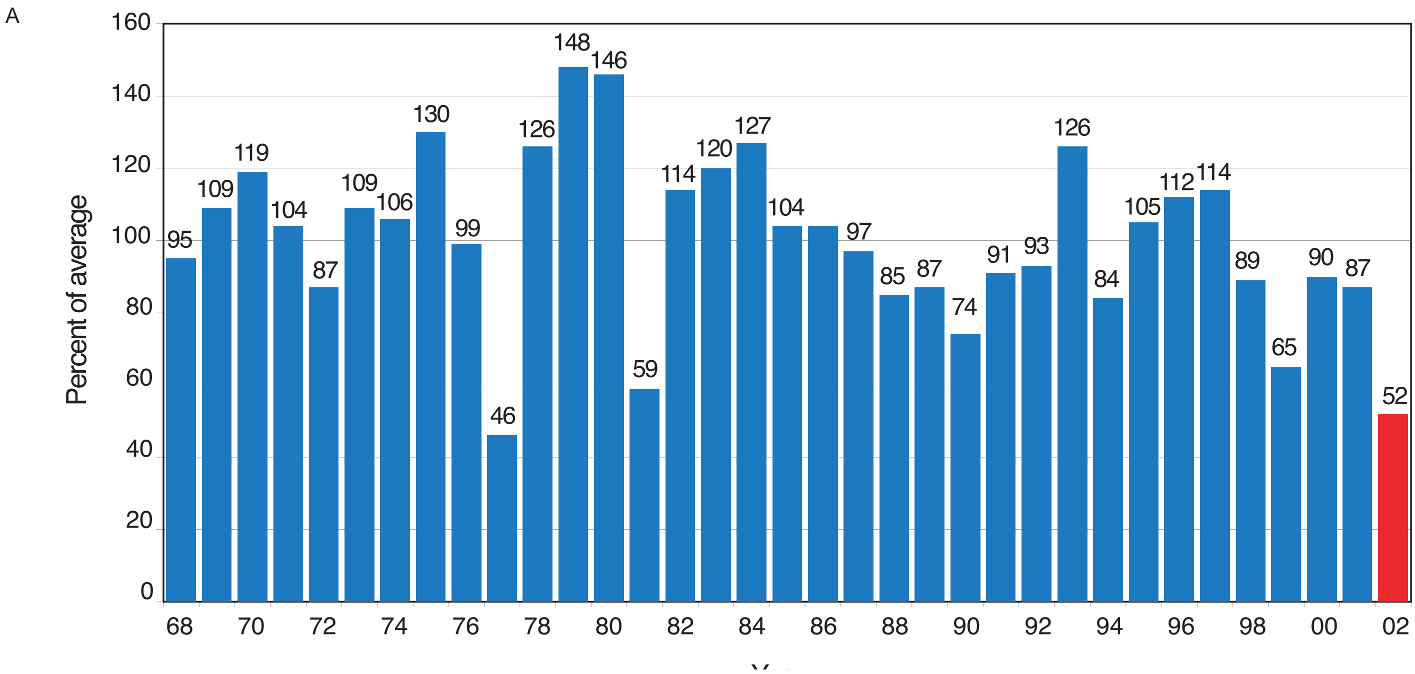
There is increasing recognition amongst many in the scientific community that the components of the Earth System are intimately connected, and that interactions extend from local to global scales. This is clearly articulated in the recent Executive Summary of the IGBP Synthesis Book [1] which emphasises the complex, nonlinear behaviour of the Earth System, and which is based on scientific contributions from each of the IGBP projects. The recognition of the multiple interactions across space and time scales has led to a new interdisciplinary direction for IGBP, which promises to be an effective means to advance our understanding of the Earth System, and its human-caused and natural dynamics.

A Broader Perspective on Climate Change is Needed

There are significant consequences of this complexity however, which need to be more widely recognised. One consequence is that prediction (also referred to as projection), cannot by itself be the primary basis on which to plan for the future. This is discussed in another IGBP sponsored paper [2] that presents examples demonstrating that the Earth's climate system is highly nonlinear, that inputs and outputs are not proportional (change is often episodic and abrupt, rather then slow and gradual), and that multiple equilibria are the norm. One example, is the transformation of above average snow pack in the Colorado Rocky Mountains in the mid 1990s to well below average later in the decade and early 2000s (Figure 1a). This abrupt change had a very substantial effect on the reservoir water storage in this region (Figure 1b), where the available water supplies were rapidly depleted and not adequately replenished by the melting of the deficient snowpack. Such transitions in winter precipitation have not been adequately explained using climate models.

Indeed, with respect to climate projections, as we increasingly recognise the diverse, multiple types of global and regional radiative and non-radiative climate forcings, skilful forecasts of future global and regional climate become increasingly more challenging [4]. No climate change model even includes all of the important forcings and feedbacks. To accommodate this uncertainty, an approach of first assessing key societal and environmental vulnerabilities, and then seeking to determine if skilful predictions are possible has been proposed [5].

This new direction to Earth sciences has not been clearly recognised by many, particularly, in the atmospheric science and science policy communities. For example, many, if not most climate change policy studies still focus on global mean surface temperature change as the metric to link to economic impact due to anthropogenic changes in atmospheric composition [6]. Yet climate impacts extend far beyond a global mean temperature and include other anthropogenic climate forcings, such as land use change [e.g.7,8], the multiple forcings associated with aerosols [e.g.9,10] as well as complex feedbacks [11]. The perspective adopted by many in the atmospheric modelling and climate policy communities is that the global models provide skilful projections of the future, and we are just seeking to confirm them with selected observations. However, there are issues with the robustness of climate change models, as has been documented in the peer-reviewed literature [e.g.12,13]. The resistance within the atmospheric modelling community to more rigorous model testing and the general lack of effective dialog within and between disciplines, has constrained advances in our understanding. Rial and colleagues conclude that "it is imperative



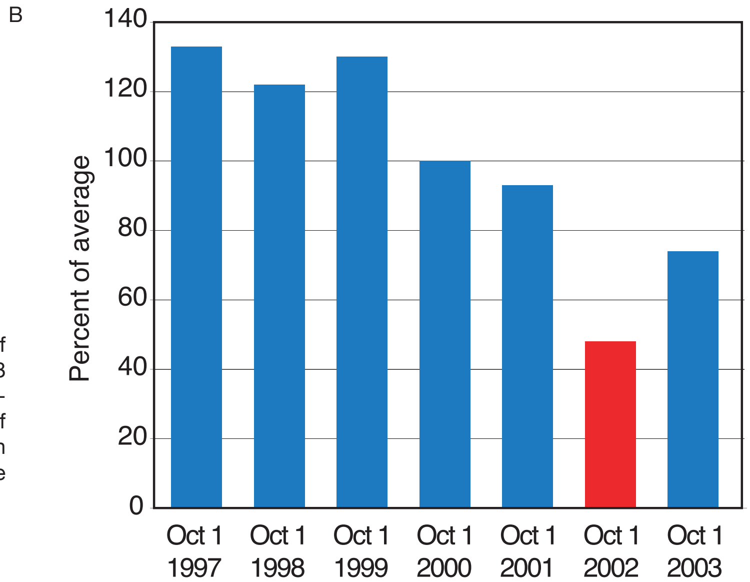


Figure 1. (a) April 1 snowpack percent of average for state of Colorado for years 1968 through 2002 [from 3]. (b) Colorado statewide reservoir storage levels as a percent of average for the end of the growing season (data provided by the Natural Resource Conservation Service, USDA).

that the Earth's climate system research community embraces this nonlinear paradigm if we are to move forward in the assessment of the human influence on climate" [2].

A new vulnerability paradigm is proposed in the BAHC Synthesis Book [14] to address the shortcoming of emphasising global model projections as the primary basis for determining the likely impacts for us of future climate. The vulnerability paradigm, as applied to the Earth System, is a more inclusive approach than prediction. Key vulnerabilities include risks, for example, to regional and global food, water and energy supplies. The environmental and human-caused threats extend well beyond climate.

An example of the application of the vulnerability paradigm is the question of whether population growth, or the climate change predicted by the atmospheric-ocean general circulation models (GCMs), poses the greater threat to potable water [15]. Figure 2 illustrates that the risk, as represented by the model forecasts, is very much dominated by population growth. Another example is the comparison of the risk from damage due to tropical cyclones based on GCM predictions, to the risk from coastal population and infrastructure growth [16]. As with the potable water situation, the larger risk is associated with human population (in this case, their migration to coastal areas) (Figure 3). With respect to the risk from tropical cyclones, the relative sensitivity of societal change to GCM-predicted climate change ranges from 22 to 1, to 60 to 1, depending on the scenarios used. The conclusion from both of these studies is that steps to modulate the future

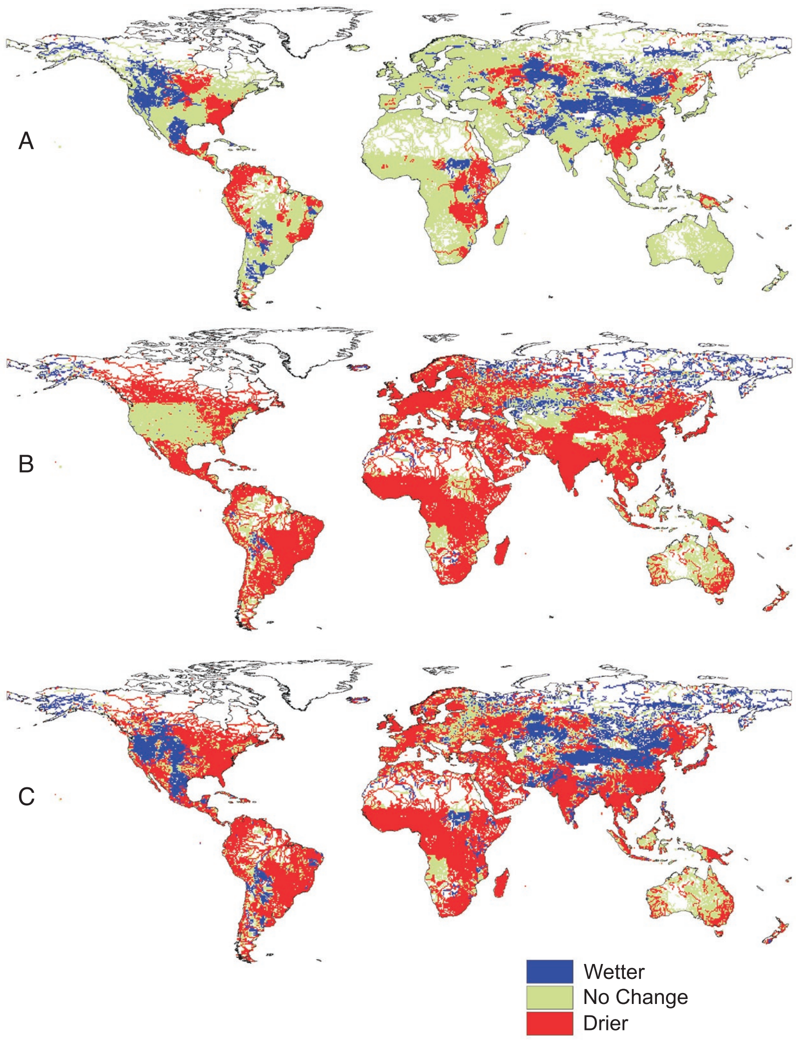


Figure 2. Maps of relative change in water reuse under (A) GCM-simulated climate change, (B) population and economic development, and (C) GCM-simulated climate change and population and economic development [from 15].

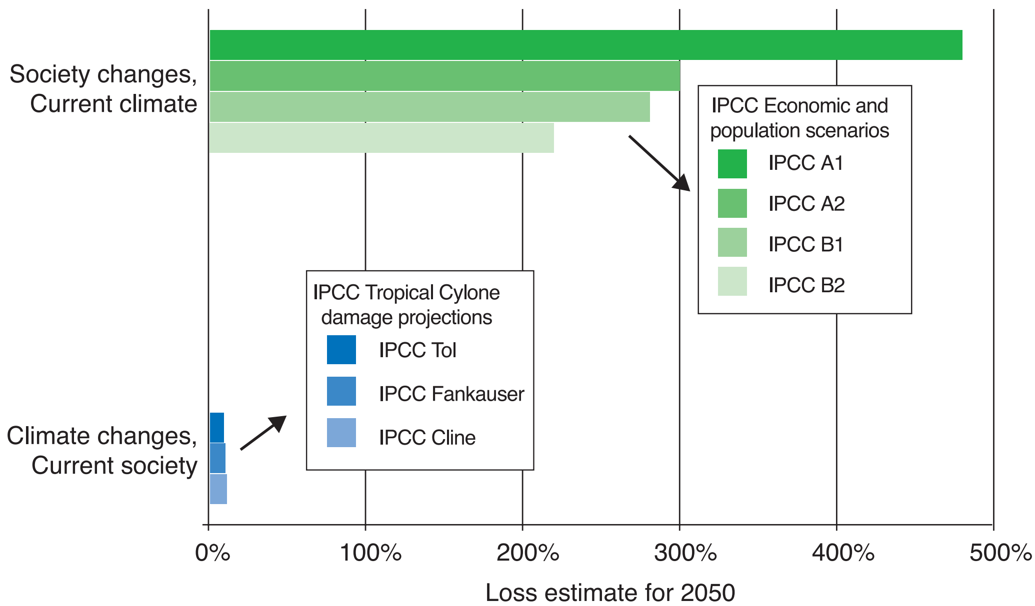


Figure 3. 2050 global tropical cyclone loss sensitivities based on IPCC scenarios and analyses [from 16].

climate via greenhouse emission reductions, based on the GCM predictions, would only address a very small portion of the future risk to potable water and tropical cyclone damage. These comparisons, of course, do not mean that human-caused climate change is not a risk, but if we accept GCM simulations as skilful projections, we actually diminish the importance of threats from climate change, which can be abrupt, but cannot be predicted.

The framework for vulnerability assessments (Figure 4) is place-based and has a bottom-up perspective, in contrast to the GCM-focus which is a top-down approach from a global perspective The vulnerability focus is on the resource of interest – water resources in the case of Figure 4. The challenge is to use resource specific models and observations to determine thresholds at which negative effects occur associated with the resource. Changes in the climate (represented therein by weather and land surface dynamics) represent only one threat to the resource; the climate itself may also be significantly altered by changes in the resource, and there are multiple, nonlinear interactions between the forcings (indicated by the dashed

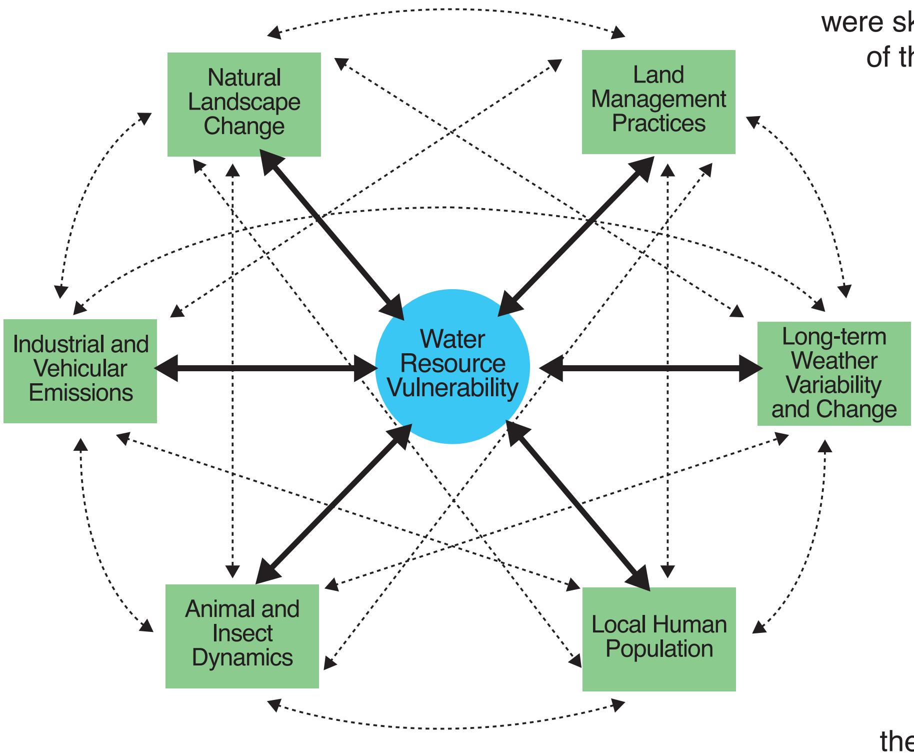


Figure 4. Schematic of the relation of water resource vulnerability to the spectrum of the environmental forcings and feedbacks [adapted from 14]. The arrows denote nonlinear interactions between and within natural and human forcings.

lines on Figure 4). The GCM models, even if they were skilful predictions, still only capture a portion of the threat to the resource.

To accommodate the perspective that the Earth System, including the climate, involves complex forcings and interactions across space and time scales, requires us to be more inclusive in the involvement of the diverse communities performing climate and environmental change research and to elevate interdisciplinary scientists to leadership roles in these communities. IGBP has been extremely successful in developing such an approach, and will continue to promote interdisciplinary and cross-project integration in the coming decade of research. Within IGBP, the emerging AIMES project (Analysis and Integrated Modelling of the Earth System) will provide one focus for investigating complex forcings and interactions within the Earth System.

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References

1. Steffen W et al. (2004) Executive Summary: Global Change and the Earth System. IGBP Secretariat, Stockholm, Sweden. ISBN 91-631-5380-7. 40 pp.
2. Rial J et al. (2004) Nonlinearities, feedbacks and critical thresholds within the Earth's climate system. Climatic Change 65, 11-38.
3. Pielke RA Sr et al. (2004) Drought 2002 in Colorado – an unprecedented drought or a routine drought? Pure and Applied Geophysics, Special Issue in Honor of Prof. Singh, accepted.
4. Pielke RA Jr. (2001) Room for doubt. Nature 410, 151.
5. Sarewitz D, Pielke RA Jr and Byerly R Jr (Eds). (2000) Prediction: Science, decision making and the future of nature. Island Press, Washington DC, 405pp.
6. Houghton JT et al. (Eds.) (2001) Climate Change 2001: The Scientific Basis – Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, UK, 881pp.
7. Marland G et al. (2003) The climatic impacts of land surface change and carbon management, and the implications for climate-change mitigation policy. Climate Policy 3, 149-157.
8. Pielke RA Sr. (2001) Earth system modelling – An integrated assessment tool for environmental studies. In: Present and Future of Modelling Global Environmental Change: Toward Integrated Modelling (Eds. T Matsuno and H Kida), Terra Scientific Publishing Company, Tokyo, Japan, 311-337.
9. Andreae MO et al. (2004) Smoking rain clouds over the Amazon. Science 303, 1337-1342.
10. Niyogi D et al. (2004) Direct observations of the effects of aerosol loading on CO_2. Geophysical Research Letters, accepted.
11. NRC. (2003) Understanding Climate Change Feedbacks. Panel on Climate Change Feedbacks, Climate Research Committee, National Research Council, USA 166 pp.
12. Pielke RA Sr. (2002) Overlooked issues in the US National Climate and IPCC assessments. Climatic Change 52, 1-11.
13. Chase TN, Pielke RA Sr, Herman B and Zeng X. (2004) Likelihood of rapidly increasing surface temperatures unaccompanied by strong warming in the free troposphere. Climate Research 25, 185-190.
14. Kabat P et al. (Eds.) (2004) Vegetation, Water, Humans and the Climate. Springer, Berlin, 566 pp.
15. Vörösmarty CJ et al. (2000) Global water resources: Vulnerability from climate change acid population growth. Science 289, 284-288.
16. Sarewitz DR, Pielke Jr RA and Keykyah M. (2003) Vulnerability and risk: some thoughts from a political and policy perspective. Risk Analysis 23, 805-810.

To avoid excessive climate change, reductions in global greenhouse gas emissions of around 50% will probably be required in the next few decades. Furthermore, the increasing pressure for significant international convergence, means that Europe and the USA may need to reduce emissions by 80-90%. This will be extremely difficult to achieve. It is unlikely, although still uncertain, that such reductions could be achieved merely by improved energy efficiencies and by the reduced carbon intensities that would stem from greater use of renewable energy sources.

Macro-Engineering Options for Climate Change Management and Mitigation

The urgency and magnitude of the response required to tackle climate-change means innovative approaches to climate change mitigation will also be needed, and indeed may even be needed during the Second Commitment Period of the Kyoto Protocol. While potential low-carbon energy sources such as nuclear fission and fusion, either already exist or may become available later this century, there is likely to be a serious shortfall in the medium-term. The feasibility of large scale deployment of "macro-engineering" options that might help close the gap should therefore be discussed widely and evaluated properly. These involve either CO_2 capture and storage (currently the subject of an IPCC special study), or deliberate modification of the albedo of the Earth ("geo-engineering").

To identify, debate, and evaluate possible macro-engineering responses to the climate change problem, the Tyndall Centre for Climate Change Research and the Cambridge-MIT Institute convened a special joint symposium on "Macro-Engineering Options for Climate Change Management and Mitigation" in January 2004. The intention of the Symposium was to initiate an open process of discussion and evaluation, so that suitable options may be identified and eventually made available, if and when required. The Symposium was of course, only one of many steps in a process that must continue for several years.

Most of the macro-engineering approaches identified are not currently considered in mainstream climate policy, but the mere fact that they have been conceived and proposed places an obligation on engineers, economists, and environmental and social scientists, to jointly explore their feasibility and evaluate their potential consequences. At the very least, such options may need to be considered as emergency policy options if adverse climate change impacts are greater than expected, or if carbon reduction measures are less effective than anticipated. Many of the possible options are highly speculative at present, and some may even appear ridiculous. However, this is precisely why they should be evaluated as soon as possible, and dismissed if necessary. Otherwise, politicians may use them as "magic bullets" to postpone action, or unrealistically suggest them as solutions for implementation.

The possible options discussed at the Symposium fell largely into two categories: (i) large-scale carbon capture and storage (sequestration) options, and the more controversial (ii) options for adjusting the planetary albedo to compensate for global warming. In the first of these categories options for both liquid and solid geological disposal were discussed, as well as options for ocean fertilisation, direct ocean disposal, atmospheric scrubbing and enhancement of land carbon sinks. In the second category options for orbiting deflection systems, stratospheric micro-balloons and aerosols, and low-level cloud stimulation were discussed (e.g. Figure 1). The Symposium also discussed in less detail other large-scale mitigation and adaptation options that do not directly address global climate management, such as land surface modification, ocean current stabilisation (by river deviation), sea-level stabilisation (by freshwater retention) and large-scale migration corridors for biosphere adaptation.

Although no attempt was made to agree upon formal conclusions or recommendations, a considerable consensus emerged, both with respect to the probable need for macro-engineering options, and the most promising approaches. There was agreement that the scale of global greenhouse gas emission reductions that will potentially be required over the century is so great that firstly, conventional methods to reduce per capita energy use, and to reduce the carbon intensity of energy will need to be deployed globally, and pervasively throughout the economy. (This includes energy conservation and the use of renewable and low-carbon energy sources, such as greater use of nuclear power as a low-carbon electricity source.) And that secondly, it is likely that the actual extent and rate of deployment of these conventional approaches will be inadequate, and macro-engineering approaches will therefore also likely

Figure 1. Enhancement of the brightness and longevity of low-level marine stratus clouds can be achieved by generating additional sea-salt cloud condensation nuclei with wind-powered spray turbines. The photograph shows early trials of one possible method of generating additional sea-salt particles. (Photograph courtesy of John Latham and Steven Salter).

to be required. However, although all the unconventional macro-engineering approaches discussed appear to be feasible in principle, few could currently be employed at the scale necessary to have significant effect.

CO_2 capture and storage options are well suited to emissions from large fixed installations, but not to diffuse emission sources, such as transport. These approaches can also however, be used to generate low carbon fuels including hydrogen for transportation applications. CO_2 capture from ambient air and subsequent storage could be applied to diffuse emissions, however, this approach would need to be combined with a sequestration process – probably geologic or mineral. Biological sequestration techniques (including both enhanced land carbon sinks and ocean fertilisation) are ambient air capture methods, but they have relatively limited potential, as the maximum scope for mitigation is probably less than 1 Gt yr^1, and the impacts on the terrestrial and marine ecosystems are difficult to predict but may well be large. Nonetheless, land sequestration might be useful in a portfolio of methods, since both soil conservation techniques and afforestation of former agricultural land in snow-free temperate regions move the climate and the carbon cycle back towards the pre-anthropogenic state. Terrestrial ecosystems are also much better understood than marine ones, due to long-term experience in agricultural and forestry practice.

It was noted that increasing atmospheric CO_2 concentrations are not only an agent of global warming, but are also causing progressive and significant acidification of the surface waters of the oceans, with detrimental effects for calcifying organisms including corals. While albedo management options would ameliorate the warming, they would have no effect on ocean acidification. The change in ocean surface acidity will probably change emissions of other climate-relevant trace gases (e.g. dimethlysulphide and organo-halogens), and may also alter the soft-organism biological carbon pump thus altering oceanic CO_2 uptake and release. Substantial reductions of present and future CO_2 emissions, either directly or through CO_2 capture and storage, are therefore likely to be needed to avoid excessive ocean acidification, even if albedo adjustments are used to manage warming. These adverse marine effects must however, be set against the associated possible benefits of probable increased biological productivity on land. Ultimately it may be possible to agree upon a compromise target CO_2 level, since there is no reason to suppose that the current, or even pre-industrial level, should be the target.

While the several options for albedo adjustment are promising, their potential effects on air quality – through changes in atmospheric chemistry, particularly effects on oxidants such as the hydroxyl radical – are poorly understood and should be carefully investigated. Consideration of options for sea-level stabilisation led to agreement that in this case it is best to deal with the causative factors, rather than to sequester freshwater by artificial impoundment. The latter approach is unlikely to be feasible or effective on the scale required, and could have major terrestrial and social impacts.

For all unconventional options, but especially albedo modification, extensive further research and development is necessary. In addition, political, ethical and socio-economic analyses are required before large-scale implementation could be considered. Such studies, involving discussions with representatives of all groups impacted, should be encouraged and funded at realistic levels. Any attempts to deliberately modify the environment should be subject to the modern (medical) ethical principle of "first, do no harm". Macro-engineering options will require large-scale tests, with extensive monitoring to determine the near- and far-field effects. Basic research should be combined with large scale pilot experiments to maximise the learning outcomes from any specific endeavour. Support for research and development programmes is therefore required if any of the macro-engineering options are to progress sufficiently to allow future implementation. However, such research must not used as a reason for delaying the implementation of proven conventional approach, or for avoiding the difficult decisions. In addition to research and development programmes, inter-disciplinary working groups should be established to carefully study all the ramifications of macro-engineering solutions (including those of any pilot studies) at both regional and global scales.

Further discussion and evaluation of macro-engineering options needs to be brought into the main-stream climate change debate. There are few institutions with the appropriate remit and range of expertise to do this, but the Tyndall Centre hopes to take a leading role in this effort, at least in the UK. Further information on the Symposium, including papers and presentations, can be found at http://www.tyndall.ac.uk/events/past_events/cmi.shtml.

John Shepherd
Tyndall Centre (South), Southampton Oceanography Centre
University of Southampton
Southampton, UK
E-mail: j.g.shepherd@soc.soton.ac.uk

New Roles and Faces

IGBP Executive Director

Professor Kevin Noone has been appointed by the Executive Board of ISCU as Executive Director of IGBP from 1 September 2004. Kevin comes to IGBP from the position of Professor of Meteorology and Head of the Atmospheric Physics Division at the Department of Meteorology, Stockholm University. He has a BSE in Chemical Engineering, and MSE and PhD degrees in Civil and Environmental Engineering from the University of Washington in Seattle, WA (USA). He was on the faculty at Stockholm University (Sweden) from 1987-91, and was a research scientist and Adjunct Professor of Oceanography at the Center for Atmospheric Chemistry Studies, Graduate School of Oceanography at the University of Rhode Island (USA) from 1992-1995.

Kevin's primary research interests are in the area of aerosol-cloud interactions, multiphase chemical processes, and the effects of aerosols and clouds on the Earth's climate. He has been part many large international field programs, including several sponsored by IGBP. He is (or has been) a member of several international committees, including the Eurotrac-2 Scientific Steering Committee, coordinating the Aerosols project within the EU ACCENT Network of Excellence, and the International Commission on Clouds and Precipitation (ICCP). He is Associate Editor of the journals Ambio and Atmospheric Research.

We welcome Kevin to IGBP and to the office of the Secretariat in Stockholm.

E-mail: zippy@igbp.kva.se

Co-Chairs of the Global Water System Project

The Chairs and Directors of the global change programmes of the Earth System Science Partnership have appointed Joseph Alcamo and Charles Vörösmarty as Co-Chairs of the Scientific Steering Committee of the Global Water System Project (GWSP).

Joseph Alcamo is Executive Director of the Center for Environmental Systems Research at the University of Kassel in Germany, where he is leader of a research group on global and regional environmental dynamics, that concentrates on the development of innovative approaches in integrated global and regional modelling and their application to environmental policy making. Amongst several international roles, Joseph is a Co-ordinating Lead Author for the Intergovernmental Panel on Climate Change.

E-mail: alcamo@usf.uni-kassel.d

Charles Vörösmarty is Director of the Water Systems Analysis Group in the Institute for the Study of Earth, Oceans and Space, at the University of New Hampshire, USA. Charles served from 1993-2002 on the Scientific Steering Committee for IGBP's former Biospheric Aspects of the Hydrological Cycle project. His research focuses on the development of computer models and geospatial data sets used in synthesis projects that consider interactions between the water cycle, climate, biogeochemistry and anthropogenic activities. He is a Convening Lead Author on one of the Millennium Assessment working groups.

E-mail: charles.vorosmarty@unh.edu

GWSP Deputy Executive Officer

Marcel Endejan has been appointed on a two year contract from 1 September 2004 as the Deputy Executive Officer for the Global Water System Project (GWSP) of the Earth System Science Partnership. Marcel has a first degree in informatics and a Masters degree in environmental monitoring. His PhD (awarded 2003) was on the software architecture for integrated assessment models on global change. Marcel comes to Bonn from the Center for Environmental Systems Research at the University of Kassel, where he worked with GWSP Co-Chair Joseph Alacmo on a variety of global land and water modelling and assessment projects.

E-mail: marcel.endejan@uni-bonn.de

IGBP and Related Global Change Meetings

A more extensive meetings list is held on the IGBP web site at www.igbp.kva.se

5th International Conference "Asian Mega-cities and Sustainability"

10-12 November, Tokyo, Japan

Contact: Kiyoshi Kurokawa, kurokawa@is.icc.u-tokai.ac.jp

RUPSUR 3rd Meeting "Biophysical and Socioeconomic Impacts of ENSO on Marine and Terrestrial Ecosystems"

11-12 November, Santiago, Chile

Contact: http://www.udep.edu.pe/rupsur/

European Conference on Coastal Zone Research: an ELOISE Approach

15-18 November, Portoroz, Slovenia

Contact: http://www2.nilu.no/eloise/

Global Carbon Project Workshop: "Regional Carbon Budgets: from methodologies to quantification"

15-18 November, Beijing, China

Contact: Pep Canadell, pep.canadell@csiro.au

RMS/UK SOLAS Meeting

17 November, London, UK

Contact: David Woolf, dkw@soc.soton.ac.uk

2nd China-Japan-Korea Joint GLOBEC Symposium

27-29 November, Hangzhou, China

Contact: Ling Tong, tongling@ysfri.ac.cn

Conference on the Human Dimensions of Global Environmental Change

03-04 December, Berlin, Germany

Contact: Klaus Jacob, jacob@zedat.fu-berlin.de, Daniel Pentzlin, BC2004@zedat.fu-berlin.de, Daniel Pentzlin, BC2004@zedat.fu-berlin.de, http://www.fu-berlin.de/ffu/akumwelt/bc2004/index.htm

AGU Fall Meeting

13-17 December, San Francisco, USA

Contact: http://www.agu.org/meetings/fm04/

Joint IGAC/NOAA/NASA meeting on the Aerosol Indirect Effect

05-07 January, Manchester, UK

Contact: http://www.al.noaa.gov/igac/

85th AMS Annual Meeting: Building the Earth Information System

09-13 January, San Diego, CA, USA

Contact: http://www.ametsoc.org/MEET/85annual/index.html

International Conference on Integrated Assessment of Water Resources and Global Change: a North-South Analysis

23-25 February, Bonn, Germany

Contact: http://www.zef.de/watershed2005

PAGES/DEKLIM Conference: "The climate of the next millennia in the perspective of abrupt climate change during the late pleistocene"

07-10 March, Mainz, Germany

Contact: Saskia Rudert, rudert@uni-mainz.de, http://www.uni-mainz.de/FB/Geo/Geologie/sedi/en/index.html

7th IAHS Scientific Assembly

03-09 April, Foz do Iguacu, Brazil

Contact: http://www.acquacon.com.br

European Geosciences Union General Assembly

25-29 April, Vienna, Austria

Contact: http://www.copernicus.org/EGU/ga/egu05/index.htm

1st Alexander von Humboldt International Conference

16-20 May, Guayaquil, Ecuador

Contact: http://www.copernicus.org/EGU/topconf/avh1/

International Symposium on Arid Climate Change and Sustainable Development

May, Lanzhou, Gansu, P.R. China

Conatct: Bi Xiaodong, Ebxd_2463@sohu.com, Guo Hui, Guoh_lz@sina.com, Yao Hui, ISACS@gsma.gov.cn

International GLOBEC Symposium: Climate Variability and Sub-Arctic Marine Ecosystems
16-21 May, Victoria, Canada
Contact: GLOBEC IPO, globec@pml.ac.uk, http://www.globec.org

Living with global change: Challenges in environmental sciences
30 May-01 June, Rehovot, Israel
Contact: Dan Yakir, dan.yakir@weizmann.ac.il

The Oceanography Society and UNESCO/IOC International Ocean Research Conference
06-10 June, Paris, France
Contact: http://www.tos.org/conference.htm

97th Dahlem Workshop
12-17 June, Berlin, Germany
Contact: dahlem@zedat.fu-berlin.de

Rapid Landscape Change and Human Response in the Arctic
15-17 June, Whitehorse, Yukon, Canada
Contact: Antony Berger, bergerar@telus.net

Human Security and Climate Change: An International Workshop
21-23 June, Oslo, Norway
Contact: http://www.cicero.uio.no/humsec/

Land-Ocean Interactions in the Coastal Zone LOICZ II Inaugural Open Science Meeting
27-29 June, Egmond aan Zee, The Netherlands
Contact: http://www.loicz.org/conference

Non-CO_2 Greenhouse Gases (NCGG-4)
04-06 July, Utrecht, The Netherlands
Contact: http://www.milieukundigen.nl/pages/ncgg4/

IAMAS Symposium
02-11 August, Beijing, China
Contact: http://web.lasg.ac.cn/IAMAS2005/program.htm

2nd PAGES Open Science Meeting
10-12 August, Beijing, China
Contact: PAGES IPO, pages@pages.unibe.ch, http://www.pages2005.org/

Holivar and CLIVAR/PAGES Open Science Meeting
September, TBA
Contact: Rick Battarbee, r.battarbee@ucl.ac.uk

7th International CO_2 Conference
26-30 September, Boulder, Colorado, USA
Contact: Pep Canadell, pep.canadell@csiro.au

6th Open Meeting of the Human Dimensions Global Environmental Change Research Community
09-13 October, Bonn, Germany
Contact: http://www.ihdp.org

International Conference on

Integrated Assessment of Water Resources and Global Change: A North-South Analysis

Bonn, Germany
23-25 February, 2005

Objective and themes of the conference

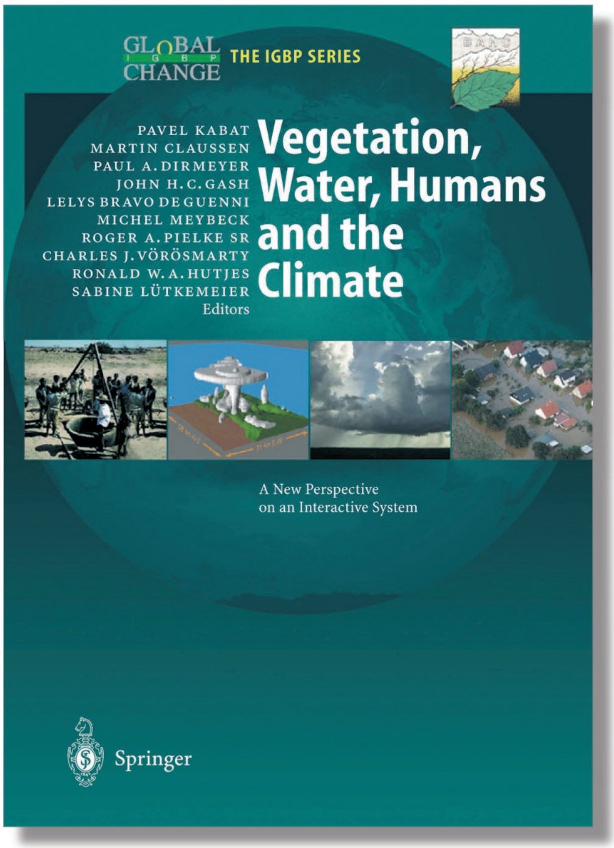
The main objective of the conference is to analyse the global change challenges that are encountered in the integrated assessment and management of water resources in large river basins. By bringing together scientists and managers from North and South, it is expected that international research efforts concerning water related issues will be translated into more practical methods and coherent approaches.

At the conference, the following themes will be addressed explicitly:

* **Water resources data**
* **Stakeholders perspectives**
* **Scaling**
* **Integration**
* **Water science and policy**
* **Summary of international water programs**

CGIAR Challenge Program on WATER & FOOD · IAHS AISH · GWSP · UNESCO · Bundesministerium för Bildung und Forshung · GLOWA

www.zef.de/watershed2005



Vegetation, Water, Humans and the Climate

Editors: P Kabat, M Claussen, PA Dirmeyer, JHC Gash, LB de Guenni, M Meybeck, RA Pielke Sr, CJ Vörösmarty, RWA Hutjes and S Lütkemeier

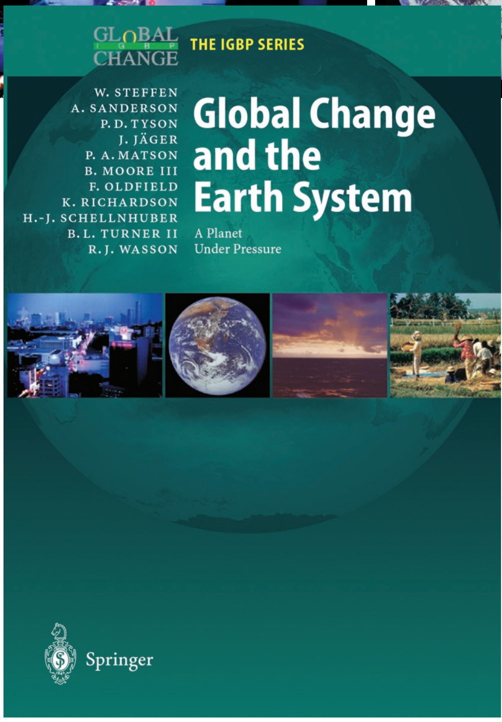
ISBN: 3-540-42400-8 (129.95 Euro)

The BAHC Synthesis book is now available from Springer. To order on-line follow the links from the IGBP home page to 'Products' and 'Book Series'. This 550+ page summarises over a decade of research of the *Biospheric Aspects of the Hydrologic Cycle* (BAHC) project of IGBP. It also encompasses relevant related research especially many of the findings of the *Global Energy and Water Cycle Experiment* (GEWEX) project of WCRP.

The book describes the interactions between the terrestrial biosphere and the atmosphere via the hydrological cycle, and their interactions with human activities. Measurements from field experiments are complemented by modelling studies simulating flows and transport in rivers, coupled land-cover and climate, and Earth System processes. The impact of humans on river basins, environmental vulnerability, and methods for assessing the risks associated with global change are discussed.

Springer · GLOBAL CHANGE IGBP

Our Changing Planet



Global Change and the Earth System: A Planet Under Pressure

Editors: W Steffen, A Sanderson, PD Tyson, J Jäger, A Matson, B Moore III, F Oldfield, K Richardson, H.J. Schellnhuber, BL Turner II, RJ Wasson

ISBN: 3-540-40800-2 (99.95 Euro)

This book presents our current understanding of the Earth's environment as a single, integrated system, and is based on a decade of IGBP and related research. It explores the functioning of the Earth System before humans, and the ways in which human activities have grown to cause changes that reverberate through the System.

You can also download a 40 page Executive Summary from the IGBP website. For hardcopies please contact the IGBP Secretariat (charlotte@igbp.kva.se)

Springer

GLOBAL IGBP CHANGE

PAGES 2nd Open Science Meeting 10-12 August, 2005 Beijing, China

Second Open Science Meeting
Paleoclimate, Environmental Sustainability and our Future
PAGES
10-12 August 2005, Beijing, China

Palaeoclimate, Environmental Sustainability and Our Future

Meeting Themes

- Future Change: Historical Understanding
- Humans and their Environment: Past Perspectives on Sustainability
- Ocean-Continent-Cryosphere Interactions: Past and Present
- Climate, Humans and the Environment in Asia
- PAGES Research Foci and Initiatives within IGBPII

Poster abstract submission deadline 31 March 2005

Early registration before 15 May 2005

The OSM will consist of plenary lectures and poster sessions. See the preliminary program at www.pages2005.org/schedule.html.

The PAGES OSM is being held alongside the 9th IAMAS Scientific Assembly (2-11 August 2005).

GLOBAL IGBP CHANGE

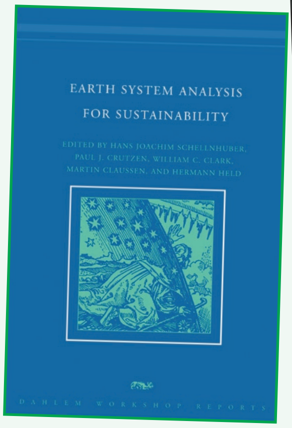
www.pages2005.org

PAGES
PAST GLOBAL CHANGES

Pin Board

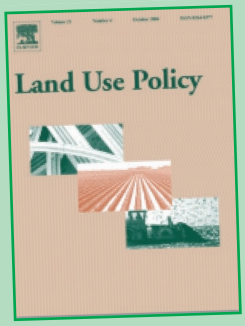
The Pin Board is a place for short announcements and letters to the Editor. Announcements may range from major field campaiyns new websites, research centres, collaborative programmes, policy initiatives or political decisions of relevance to global change. Letters to the Editor should not exceed 200 words and should be accompanied by name and contact details.

New Dahlem Workshop Report Published



Published in September 2004 and edited by Hans Joachim Schellnhuber, Paul J. Crutzen, William C. Clark, Martin Claussen and Hermann Held, Earth System Analysis for Sustainability, uses an integrated systems approach to provide a panoramic view of planetary dynamics since the inception of life some four billion years ago and to identify principles for responsible management of the global environment in the future. Perceiving our planet as a single entity with hyper-complex, often unpredictable behaviour, the authors use Earth System analysis to study global changes past and future. They explore the question of whether the unprecedented human-originated changes transforming the ecosphere today will end a 10,000-year period of climate stability. The book presents the complete story of the inseparably intertwined evolution of life and matter on Earth, focusing on four major topics: long-term geosphere-biosphere interaction and the possibility of using extrasolar planets to test various geophysical hypotheses; the Quaternary Earth System's modes of operation; current planetary dynamics under human pressure; and transition to global sustainability.

Special Issue of Land use Policy



The LUCC-endorsed project "Land Use Change and Socio-Economic Metabolism" has, together with colleagues from the Global Footprint Network and the Institute of the ecology and Conservation Research of the University of Vienna, produced a special issue of the Elsevier journal Land Use Policy (Volume 21 Number 3) entitled "Land Use and Sustainability Indicators". The Guest Editors for the issue are Helmut Haberl, Mathias Wackernagel and Thomas Wrbka. The issue is comprised of ten articles including an introductory article. For a listing of contents visit Elsevier's Science Direct website http://www.sciencedirect.com.

IGBP at EuroScience Open Forum

The first Euroscience Open Forum was held in Stockholm, Sweden during August 2004; more than 1,800 people participated, including 350 international journalists. This was the first pan-European scientific meeting staged to provide an interdisciplinary forum for open dialogue, debate and discussion on science and technology in society.

Susannah Eliot from the IGBP Secretariat organised a special session for the Forum: Beyond global warming: where on Earth are we going? The session was moderated by the new IGBP Executive Director, Kevin Noone, and comprised the following six presentations:

How stable is the Earth System?
Will Steffen (International Geosphere-Biosphere Programme, Sweden)

Switches and choke points in the Earth System: the planet's Achilles' heels.
John Schellnhuber (Tyndall Climate Change Centre, UK)

Abrupt climatic change: are the Pentagon and Hollywood right?
Stefan Rahmstorf (Potsdam Institute of Climate Impact Research, Germany)

Atmospheric chemistry in the Anthropocene
Paul Crutzen (Max-Planck Institute for Chemistry, Germany)

Global change and the future of oceans
Katherine Richardson (Aarhus University, Denmark)

Institutional challenges: preparing science to tackle abrupt changes
Uno Svedin (International Group of Funding Agencies, Sweden)

More information on the Forum can be found at www.esof2004.org, including links to the ICSU website from where the presentations for the above session can be downloaded. The next Euroscience Forum will be held Munich, 2006 (see www.esof2006.org).

GWSP Update

The Global Water System Project is rapidly taking shape with appointment of Co-chairs (see New Roles and Faces) and executive members of its Scientific Steering Committee (SSC), and a Deputy Executive Officer (see New Roles and Faces) for the International Project Office in Bonn. The Executive of the SSC and IPO staff met recently to agree on SSC membership nominations for consideration by the ESSP Chairs and Directors, and to discuss how the SSC and the IPO will operate.

As well as this internal business, the project has also begun to raise its external profile through an up-dating of its website (www.gwsp.org), distribution of it first electronic Newsletter, production of a brochure, and poster displays at the World Water Symposium in Stockholm, Sweden, during August. More details can be found on the website, or contact Lara Wever at the IPO (lara.wever@uni-bonn.de).

Russia Decides to Ratify

The Russian cabinet has decided to forward the 1997 Kyoto Protocol on climate change to the Russian Parliament for ratification. Assuming the Parliament does ratify the Protocol would enter into force, and international cooperation on reducing greenhouse gas emissions would be re-energised.

The Protocol contains legally binding emissions targets for 36 industrialised countries. These countries are to reduce their collective emissions of six key greenhouse gases by at least 5% by 2008-2012, compared to 1990 levels. While developing countries do not now have specific emissions targets,

they too are committed under the 1992 Climate Change Convention to taking measures to limit emissions; the Protocol will open up new avenues for assisting them to do so.

The first five-year target period is only a first step, and in addition to setting targets, the Protocol encourages governments to cooperate with one another, improve energy efficiency, reform the energy and transportation sectors, promote renewable forms of energy, phase out inappropriate fiscal measures and market imperfections, limit methane emissions from waste management and energy systems, and manage carbon "sinks" such as forest, croplands and grazing lands.

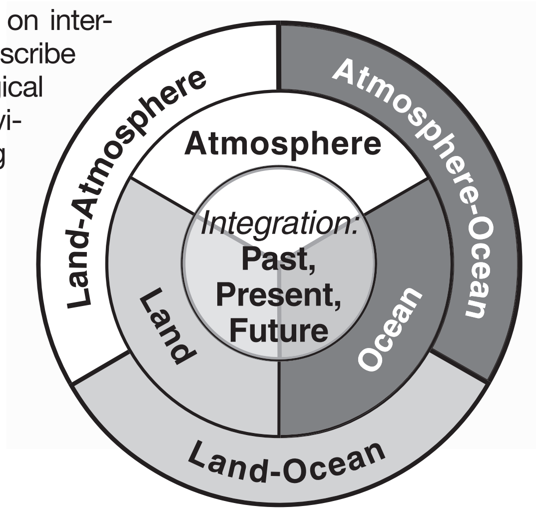
Governments will discuss their efforts to achieve their Kyoto targets and other actions to address climate change at the next major conference in Buenos Aires from 6-17 December (the 10th Session of the Conference of the Parties to the Convention). Talks on commitments for the post-2012 period are to start in 2005.

Editors Note

Contributors and readers are alerted to the fact that from this issue onwards, citations in Global Change NewsLetter articles that have more than three authors (or editors) will be listed as Primary Author et al.

The International Geosphere-Biosphere Programme

IGBP is an international scientific research programme built on interdisciplinarity, networking and integration. IGBP aims to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth System, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions. It delivers scientific knowledge to help human societies develop in harmony with Earth's environment. IGBP research is organised around the compartments of the Earth System, the interfaces between these compartments, and integration across these compartments and through time.



IGBP helps to

- develop common international frameworks for collaborative research based on agreed agendas
- form research networks to tackle focused scientific questions and promote standard methods
- guide and facilitate construction of global databases
- undertake model inter-comparisons
- facilitate efficient resource allocation
- undertake analysis, synthesis and integration of broad Earth System themes

IGBP produces

- data, models, research tools
- refereed scientific literature, often as special journal editions, books, or overview and synthesis papers

- syntheses of new understanding on Earth System science and global sustainability
- policy-relevant information in easily accessible formats

Earth System Science

IGBP works in close collaboration with the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Programme (WCRP), and DIVERSITAS, an international programme of biodiversity science. These four international programmes have formed an Earth System Science Partnership. The International Council for Science (ICSU) is the common scientific sponsor of the four international global change programmes.

Participate

IGBP welcomes participation in its activities – especially programme or project open meetings (see meetings list on website). To find out more about IGBP and its research networks and integration activities, or to become involved, visit our website (www.igbp.kva.se) or those of our projects, or contact an International Project Office or one of our 78 National Committees.

Contributions

The Global Change NewsLetter primarily publishes articles reporting science undertaken within the extensive IGBP network. However, articles reporting interesting and relevant science undertaken outside the network may also be published. Science Features should balance solid scientific content with appeal to a broad global change research and policy readership. Discussion Forum articles should stimulate debate and so may be more provocative. Articles should be between 800 and 1500 words in length, and be accompanied by two or three figures or photographs. Articles submitted for publication are reviewed before acceptance for publication. Items for the Pin Board may include letters to the Editor, short announcements such as new relevant web sites or collaborative ventures, and meeting or field campaign reports. Pin Board items should not exceed 250 words.

Photographs should be provided as tiff files; minimum of 300 dpi. Other images (graphs, diagrams, maps and logos) should be provided as vector-based .eps files to allow editorial improvements at the IGBP Secretariat. All figures should be original and unpublished, or be accompanied by written permission for re-use from the original publishers.

The Global Change NewsLetter is published quarterly – March, June, September and December. The deadline for contributions is two weeks before the start of the month of publication. Contributions should be emailed to the Editor.

ICSU
International Council for Science

ISSN 0284-5865

Publication Details

Published by:

IGBP Secretariat
Box 50005
SE-105 05, Stockholm
SWEDEN

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The current and past issues of the Global Change NewsLetter are available for download from www.igbp.kva.se. Requests for reproduction of articles appearing in the NewsLetter should be emailed to the Editor. Changes to address information for receipt of the NewsLetter should be emailed to charlotte@igbp.kva.se. The IGBP Report Series is published in annex to the Global Change NewsLetter.

Printed by Bergs Grafiska, Sweden.