

Integrated Land Ecosystem - Atmosphere Processes Study

iLEAPS



Newsletter

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Permafrost and the Arctic

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Although budget constraints usually limit our ability to fund visitors, we provide for the office and computational needs of visitors who come with independent salary support.

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- SUMMARIES presenting synthesis of recent scientific development in land-atmosphere research
- POSITION PAPERS stating views and directions in scientific research
- REPORTS presenting key scientific outcomes of programmes, workshops, or meetings.

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Editorials are around 500 words with or without one accompanying figure. Editorials are by invitation and feature a personal interpretation and evaluation on the theme of the issue.

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- ACTIVITIES report and commentaries
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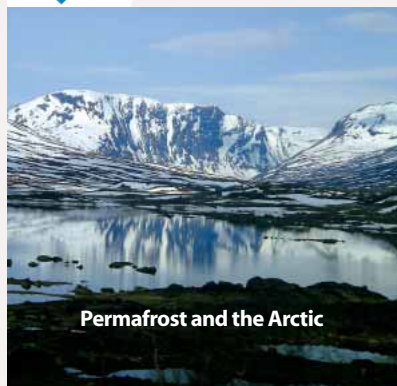
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Ilpo Koskinen, Kimarko
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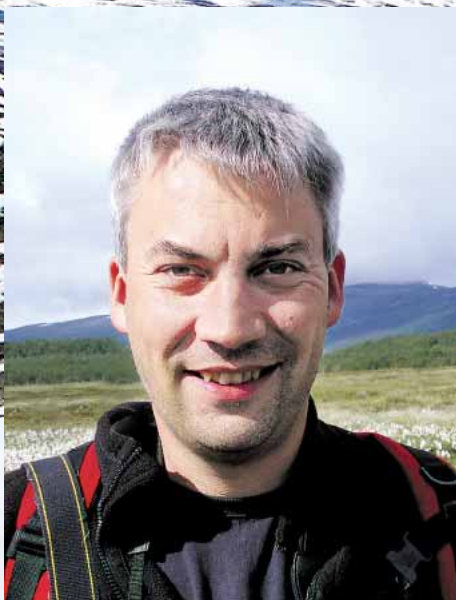
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From the midst of the Age of the Arctic



Editorial

Guest Editor Torben R. Christensen

The term “Age of the Arctic” was introduced by Professor Oran Young almost 25 years ago when he envisioned increasing public awareness of political, economic and environmental issues relating to the Arctic in the decades to come.

This prediction is now well into fulfillment with ongoing climate change in the Arctic that holds great implications for global environmental and economic issues. With increased mineral exploitation becoming possible as the Arctic sea ice redraws and increased traffic on Arctic shipping routes, the geopolitical scene at large has seen a revitalisation in the Arctic.

Also many environmental concerns follow. These range from the direct pressures on the fragile environment by mineral exploitation to those relating to loss of biodiversity as habitats for plants and animals, as a consequence of climate warming, diminish and in some cases disappear.

Somewhere within all the changes that affect snow, ice, permafrost, and vegetation distributions, a suite of changes to ecosys-

tem biogeochemical cycling is happening. These may hold less visible effects compared with the suffering polar bear sitting on a small melting block of sea ice but nonetheless they include potentially very important feedback mechanisms in the climate system.

So the Age of the Arctic goes beyond the geopolitical and overarching environmental political issues and includes global biogeochemistry. With global warming becoming all the more evident and possibly happening “first in the world” in the Arctic (see an article by J. E. Walsh on page 10 in this issue), there is a special obligation to, firstly, monitor and study how the Arctic environment is changing and, secondly, improve our process understanding of how these changes (often based on biochemistry) are affecting and feeding back to the climate system. From this improved knowledge, better platforms for predictive modelling should grow.

In this issue of the iLEAPS Newsletter, we cover and briefly review a range of topics that are relevant for the changing Arctic and

that have important implications for global biogeochemical cycling. We are going beyond the largely terrestrial iLEAPS agenda and take on board ocean processes as well. That terrestrial processes cannot be isolated from the oceanic is evident globally but, in particular, in the Arctic.

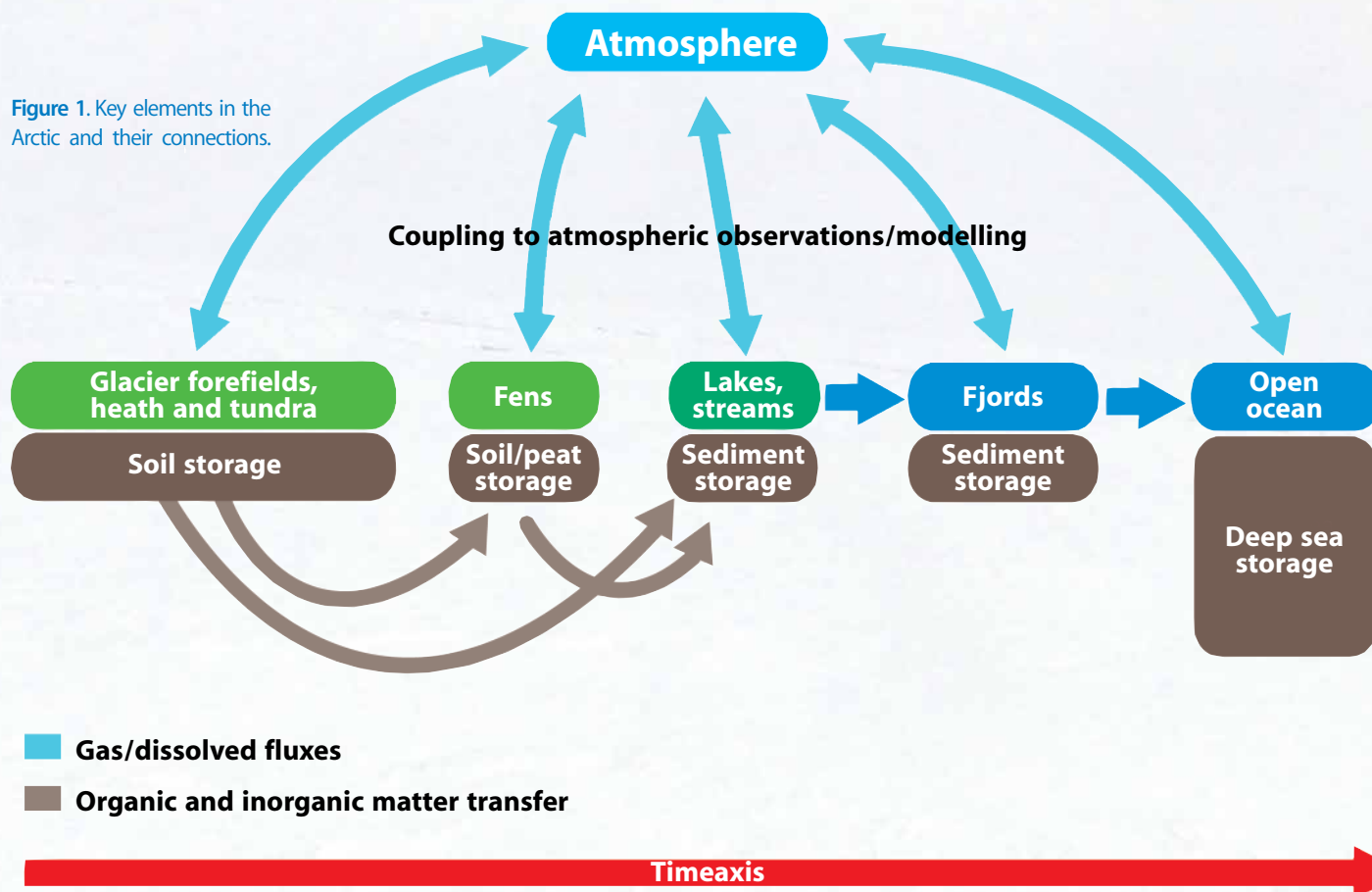
Improved understanding of biogeochemical cycling and of associated feedback mechanisms in a changing climate will have to be led by efforts that combine terrestrial, freshwater, and oceanic studies. Particularly important are those that work with transport processes between these. Key biogeochemical substances and their interactions with the atmosphere are also crucial.

A schematic model for these connections is provided in Fig. 1. I hope that we will see more studies from the empirical and modelling communities that aim at quantifying the arrows in this figure and also address their combined dynamics. ■

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Figure 1. Key elements in the Arctic and their connections.





Kathy Hibbard received her PhD at Texas A&M University in 1995 where she examined the consequences of management practices (fire suppression, heavy grazing) on woody plant encroachment. Later, she worked as a post-doctoral research associate in the College of Forestry at the University of Montana where she was involved in the Vegetation/Ecosystem Modelling and Analysis Project (VEMAP).

In 1998, Dr. Hibbard moved to the University of New Hampshire as Research Scientist and worked for the International Geosphere-Biosphere Programme (IGBP) Global Analysis and Integration of Models (GAIM) Task Force and was in the group launching the international Global Carbon Project. In 2005, Dr. Hibbard became Executive Officer for the IGBP core project AIMES (Analysis, Integration and Modelling of the Earth System) [1]. The primary focus of AIMES is to understand and integrate human-environmental processes (e.g. land use, emissions) in Earth System modelling.

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Terrestrial permafrost carbon in the changing climate

Introduction

The IPCC Working Group I Fourth Assessment Report [1] highlighted the cryosphere as a major source of uncertainty in global climate projections. One of the most significant knowledge gaps related to cryosphere is the influence of thawing permafrost on the global carbon cycle.

The magnitude of the positive feedback between the warming climate and additional emission of greenhouse gases into the atmosphere from natural sources, and particularly from thawing permafrost, is unknown. Some scientists believe the effect may be catastrophic, while others are skeptical about its significance.

The picture is complicated by limited information on the quantity and form of

carbon sequestered in permafrost, by inadequate knowledge of arctic biogeochemistry, and by insufficient understanding of the interactions between the terrestrial cryosphere, hydrology and vegetation in northern high latitudes (NHL) in the warming climate.

Physical characteristics of permafrost

Definitions and background

Permafrost is present within rock, sediment or any other earth material whose temperature remains below 0°C for two or more years. Terrestrial permafrost zones occupy up to 24% of the exposed land area of the Northern Hemisphere [2].

Permafrost temperature, thickness, and geographic continuity are controlled to a

large extent by the surface energy balance and thus vary strongly with latitude. Permafrost ranges from very cold (temperatures of -10°C and lower) and very thick (more than 500 meters and as much as 1400 meters) in the Arctic and boreal forest/taiga areas under continental climate, to warm (within one or two degrees of the melting point) and thin (several metres or less in thickness) in subarctic and some other areas.

Permafrost can be classified into two types: continuous and discontinuous. In the continuous permafrost zone, permafrost occupies the entire area (except beneath large rivers and deep lakes) and is characteristic for all types of landscapes. In the discontinuous permafrost zone, including the sporadic zone, anywhere from less than 1 to 90% of the surface is underlain by permafrost.

Recent observations indicate a warming of permafrost in many northern and mountain regions with resulting degradation of ice-rich and carbon-rich permafrost [3]. Permafrost temperature has increased by 1 to 2°C in northern Russia during the last 30 to 35 years. This observed increase is very similar to what has been observed in Alaska where the detailed characteristic of the warming varies between locations, but is typically from 0.5 to 2°C (SC Walsh: see page 10 of this issue).

In the Arctic, projected warming during the 21st century may ultimately result in the disappearance of the warmer and thinner permafrost in the southernmost zones [4]. Recent studies revealed active permafrost degradation in Alaska, Canada, Russia, Mongolia, China and Scandinavia [5–10].

If recent trends continue, it will take less than a century for permafrost in the present discontinuous zone to disappear completely in some of the areas where it is actively warming and thawing [11] (SC Walsh: see page 10 of this issue). However, the negative consequences of this degradation may be pronounced from the very beginning because the highest ice and carbon content in permafrost usually is found in the upper few tens of meters.

Quantities

The total pool of organic carbon stored in permafrost is composed of carbon frozen at depth in peatlands (concentrations from 20% to 60% C) and carbon intermixed with mineral soils (<1% to >30% C). The estimated size of the permafrost carbon pool can vary depending on the regions under consideration and on the depth of the permafrost included [12].

Total soil carbon in the northern circumpolar permafrost zone is currently estimated at 1672 billion metric tons [13]. Under a warming climate, release of carbon from permafrost to the atmosphere will occur primarily through accelerated microbial decomposition of organic matter.

However, the rate and form of this carbon release will depend on landscape-level processes (including the rate and forms of permafrost degradation) that are not very well understood quantitatively [13].

Processes

The patterns of permafrost distribution, especially in the discontinuous zone, are

determined to a large extent by local factors. In upland areas, permafrost is more common on north-facing slopes and less typical for south-facing slopes [14].

Snow cover, with its insulating effect, is an important factor; increased snow cover and depth is thought to have played a significant role in the warming of permafrost during the twentieth century [15], though the relative influence of snow compared to climate warming may diminish through the 21st century [16].

At the southernmost range of permafrost extent, local pockets of permafrost are typically relict features from the Little Ice Age (~1500–1850 AD), and are therefore extremely sensitive to ongoing and future climate change [17].

In continuous permafrost zones, the aggradation of permafrost can lead to the formation of ice-rich features such as layers of segregated ice in soil, pingos or ice wedges. In wetland areas in discontinuous permafrost zones, permafrost aggradation produces palsas. These are raised peat plateaus underlain by permafrost which under continental climates develop a tree cover and in oceanic climates more heath like vegetation but with the common feature that they are mixed with intervening fen areas that remain permafrost-free.

The relative importance of variable permafrost features and the processes that lead to changes are not well understood with regard to their influence on the biogeochemistry and climate systems. For example, small areas of change in wetlands and methane emissions are clearly important, however the consequences or feedbacks of landscape permafrost dynamics to climate are not understood.

Carbon stocks in permafrost-dominated areas basically exist mainly in two reservoirs: living vegetation and dead soil organic matter. In areas of continuous permafrost, in North America the vegetation cover is generally dominated by shrub or sedge tundra which has a low biomass, whereas in Siberia about half of the area of continuous permafrost is covered by boreal forest.

In areas of discontinuous permafrost, a boreal forest cover tends to dominate, interspersed with fens or bogs. Cold temperatures and the short growing season tend to retard vegetation growth rates, but low soil temperatures slow down the subsurface decomposition rates.

As a result, boreal forest and tundra biomes represent an important carbon reservoir in the present-day C cycle. The amount of carbon sequestered in living biomass in these biomes is typically small compared to that which has been stored in the soil over hundreds to thousands of years.

Increases in temperature lead to increased photosynthesis, but if permafrost thaws, it also leads to increased soil respiration rates. In areas underlain by mineral soils, it is generally assumed that increased soil respiration will dominate. On the other hand, if a surface soil organic layer is present, it has the effect of insulating the underlying permafrost from temperature increases [18].

Surface disturbances to permafrost areas, as a result of coastal or river erosion, forest fires, landslides or human activity, may result in catastrophic melt events and the development of thermokarst (re-organised landscape configuration resulting from permafrost melting) and thermal erosion, with the potential for substantial releases of carbon.

A unique situation exists in northern and central East Siberia, where large areas of the Lena, Yana, Indigirka, and Kolyma River basins are covered with deep, ice-rich deposits of frozen, wind-blown soil or *yedoma*, deposited during the glacial periods, which are high in organic matter [19].

Similar deposits but with much smaller geographical extent exist in Alaska. The thawing of *yedoma* results in the collapse of the soil and in the development of thermokarst lakes and wetlands. The anaerobic decomposition of the organic matter in the soil underlying the lakes leads to an efflux of methane bubbling up through the water, with occasional large outbursts [20].

In wetland areas, it is less clear as to whether warmer temperatures lead to increased sequestration or release of carbon [21]. It is generally found that net organic matter accumulation is greater in unfrozen bogs and fens than in neighbouring peat plateaus, suggesting that near-surface permafrost inhibits peat accumulation [17].

Thawing of the permafrost under these peat plateaus leads to the formation of collapse bogs in the centre or collapse fens at the margins, and thus a warming climate may lead to increased carbon accumulation rates in these collapse features (unless thermokarst develops with open water conditions). Yet warmer peat temperatures, greater soil aeration and greater rates of

peat decomposition may provide limits to this increase [22].

Ground water storage is an important factor; under anaerobic conditions decomposition produces methane, while under aerobic conditions it produces carbon dioxide. Downward movement of the water table is fundamentally linked to decreased methane fluxes from organic soils [21].

In a palsamire with degrading permafrost in subarctic Sweden it was found that between 1970 and 2000 this ecosystem had increased methane emissions [23] (SC Christensen: see page 28) while at the same time increased its carbon sink strength due to the melting permafrost and resulting wetter soil conditions [24]. The result in greenhouse warming terms was a net increase in radiative forcing due to a stronger impact of increased methane emissions compared with the uptake of carbon dioxide [24].

Changes in surface hydrology can thus also have a large effect; degradation and collapse of peat palsas is strongly related to changes in the water level in neighbouring river floodplains and fens [25]. Thawing of permafrost in peatlands has been found to lead to increased export of dissolved organic carbon through streamflow in Western Siberian watersheds that drain to the Arctic Ocean [26].

Finally, changes in the land cover can lead to changes in carbon cycle dynamics. The expansion of shrub tundra in the 20th century to replace grass and moss has altered the carbon balance in these areas [27]. Model-based analyses from [28] for the 21st century indicate that shrub tundra will become shrubbier, but that increases in shrubs in sedge tundra will be modest. In addition, drier conditions can lead to increased risk of fire, which can produce massive losses of carbon in very short periods of time [29].

Observational needs

To further the understanding of carbon cycle and permafrost dynamics and to support modelling efforts, a variety of observations and databases are required:

- Current spatial extent (horizontally and vertically), temperature, and ice content of northern hemisphere permafrost;

- Soil texture and hydraulic properties, and also soil permeable depth in permafrost areas, to enable realistic modelling of soil freezing and thawing and water storage;
- Spatial distribution of wetlands and organic soils (horizontally and vertically);
- Quantitative and qualitative information on the vertical distribution of carbon stocks;
- Vegetation type and coverage;
- Physiological and biological characteristics of vegetation present in permafrost areas;
- Long term (multi-year) flux measurements of energy, water, and carbon fluxes in conjunction with atmospheric and soil climate monitoring and detailed metadata on soil and vegetation characteristics across a range of permafrost-affected ecozones;
- Landscape dynamics.

The integration of information from different temporal and spatial scales has been suggested which should allow the testing of scaling approaches [30] (SC McGuire: see page 12 of this issue).

CAPER (CArbon and PERmafrost – a joint CliC-AIMES initiative

The EU project CARBO-North “Quantifying the carbon budget in Northern Russia: past, present and future” (2006–2010) [2] integrates flux measurements, carbon stock inventories, ecological understanding and Earth System and permafrost modelling (using Regional Climate Models (RCM), General Circulation Models (GCM), ecosystem models) to quantify the long-term fluxes of greenhouse gases from the Northern Russian land mass.

Results are used for integrated ecosystem modelling, calculation of net radiative effects and assessment of the sensitivity of climate model predictions to transient environmental changes.

The International Polar Year / International Permafrost Association (IPY/IPA) project CAPP “Carbon Pools in Permafrost regions” [3] aims at quantifying below-ground organic matter quantity and quality in high latitude and high altitude regions characterised by the presence of isolated to continuous permafrost.

We propose CAPER (“CArbon and PERmafrost”) – a joint activity that will promote complementary approaches for understanding and quantifying carbon cycle and permafrost dynamics across scales of observations, measurements and models for regional to global analyses and projections. The participants of CAPER are CARBO-North, CAPP, World Climate Research Programme’s (WCRP) Climate and Cryosphere project (CliC) [4] and International Geosphere-Biosphere Programme’s (IGBP) Analysis, Integration and Modelling of the Earth System project (AIMES) [1] as well as the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) [5].

One goal is to develop a coordinated modelling framework that provides parameterisation sets and submodels for soil carbon and energy dynamics that are applicable for cold region processes that can be inserted or incorporated into current and future generation land surface or ecosystem models.

Another goal of CAPER is to contribute to the land/ecology efforts of ongoing NHL projects. One example is the Arctic System Model [31] that is being developed into a regional fully coupled model (with ice, ocean, land, atmosphere, ice sheet, ecology). CAPER also aims to advance the development of Arctic processes in global climate models.

An implementation strategy includes collaboration with existing international coordinated bodies, for instance, from the observation and measurement perspective, the Global Carbon Project (GCP) [6], Northern Eurasian Earth Science Partnership Initiative (NEESPI) [7], Sustained Arctic Observing Network (SAON) [8], and from the global climate perspective the Coupled Carbon Cycle Climate Model Intercomparison Project (C⁴MIP) [9] communities.

Finally, CAPER will aim to improve the representation of key processes in RCMs and Earth System Models (ESMs), drawing on studies from local and regional observational, experimental and modelling communities through an iterative process to facilitate analyses of feedbacks between biogeochemistry and climate across scales with an emphasis on the coupled permafrost-carbon and hydrologic system. ■

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Recent and future Arctic regional climate variations

The Arctic has emerged as a focal region for the study of climate change. In the terrestrial Arctic system, the component most directly influenced by climate warming is permafrost. However, changes in temperature, precipitation, and seasonality affect hydrology and vegetation as well. The marine Arctic has received widespread attention because of the rapid retreat of sea ice during the summer season. In this overview, I describe how recent and projected Arctic climate changes on land and sea are shaped by both anthropogenic and natural forcing.

The recent pattern of Arctic temperature change over the past 60 years is shown in Fig. 1 for each of the four seasons. A feature that is clear across the seasons is that most areas in the Northern Hemisphere have experienced warming. The hemispherically averaged warming has been about 0.5°C. When observed increases of greenhouse gases over the same 60-year time period are used as input, climate models generally produce a similar warming.

In addition, the warming in all seasons tends to be greatest at high latitudes, a feature referred to as “polar amplification.” This feature also tends to appear in climate model simulations of greenhouse-driven

changes. Areas of weak cooling have occurred in all seasons, specifically over the central North Pacific Ocean and the extreme western North Atlantic Ocean offshore of the United States (Fig. 1).

However, some noteworthy differences exist among the seasons. Firstly, the overall (spatially averaged) warming is strongest in winter and weakest in summer. Secondly, the winter pattern is spatially more complex, with areas of cooling even at high latitudes, specifically over extreme eastern Russia and over Baffin Bay west of Greenland. Finally, the strongest warming has occurred primarily over northern land areas during winter but over the Arctic Ocean during autumn.

How do we explain these geographical and seasonal differences? The answers involve some scientific reasoning and some speculation.

Although the warming averaged over the Northern Hemisphere is consistent with increasing greenhouse gas concentrations in all seasons, the areas of cooling at high-latitudes during winter call for explanation. Winds associated with atmospheric circulation can have a strong effect on regional temperatures over timescales of days (“weather” variations) to decades. Large-scale modes of variability not only exist, but can

remain in a preferred phase for years and even decades, resulting in persistent departures from normal temperature and precipitation for a particular region.

Examples of these large-scale patterns include the Pacific Decadal Oscillation, which affects much of the Pacific Hemisphere, and the North Atlantic or Arctic Oscillation, which affects much of the Atlantic Hemisphere, including much of Europe and parts of northern Asia. These patterns represent “natural variations” that occur even without changes in greenhouse gas concentrations or other external forcing.

The two opposing trends in the subpolar North Pacific area (the cooling of eastern Russia and the warming of Alaska) resulted from a shift of the Pacific Decadal Oscillation in the late 1970s that brought stronger-than-normal northerly winds to eastern Siberia and stronger-than-normal southerly winds to Alaska and western North America. Nearly all of north-western North America’s warming of the past 60 years coincided with this shift.

A shift of the Arctic Oscillation during the 1980s was the main driver of the cooling over Baffin Bay and the warming over northern Eurasia. The effects of these winds dominate the effect of increased green-

house gases, especially where large land-ocean contrasts make temperatures very sensitive to wind direction.

Models also reproduce these features to varying degrees [1] although the timing of the pattern shifts cannot be expected to correspond to reality because natural or internal variability is essentially random. An averaging of many model simulations of the same period will tend to smooth out these variations, leaving as a residual the effects of external forcing such as changes in greenhouse gas concentrations.

What will the future bring? In the changes projected for the late 21st century averaged over the models used in IPCC's Fourth Assessment Report [2], cooling trends are no longer observable. In every season, all temperature changes are either zero or positive. The disappearance of sea ice in summer and autumn clearly affects the seasonal trends over the Arctic Ocean: warming is especially large in autumn and early winter and even extends into the adjacent continental areas.

This continental warming supports the hypothesis that the disappearance of sea ice may, in fact, enhance the degradation of permafrost [3]. On the other hand, the Arctic Ocean shows essentially no warming during summer because the melting sea ice keeps the water temperature close to zero. Clearly, the validity of the models' temperature projections is only as good as the simulations of sea ice.

However, even away from the oceans, the projected warming shows a polar amplification that is not inconsistent with the annual mean pattern implied by Fig. 1. The warming is generally 2 to 6°C over much of the Arctic land areas during each season.

The caveat in the simulated patterns of Fig. 2 is that they do not allow for the effects of natural variations such as the Pacific Decadal and Arctic Oscillations noted earlier. The averaging over multiple models effectively eliminates the effects of natural variations of the atmospheric circulation.

While the real world's climate will evolve through the 21st century only once, the set of climate model simulations represent a collection of plausible scenarios of 21st century climate. Each model simulation displays its own natural variations during the century. In this respect, Fig. 2 provides a background signal (of greenhouse gas-driven warming) upon which circulation-driven natural variations will be superimposed. The challenge in climate prediction is

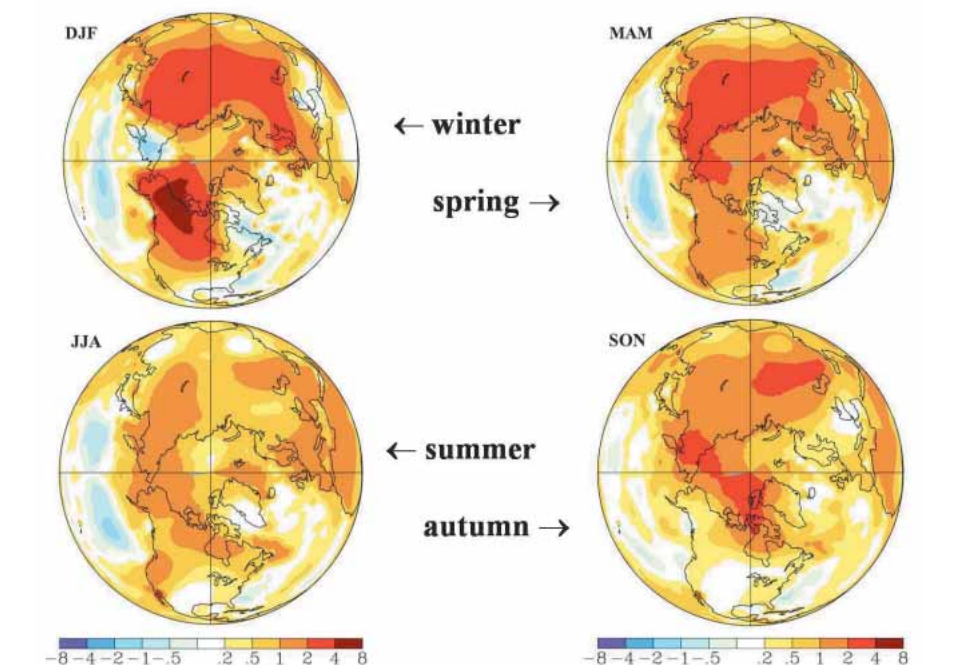


Figure 1. Arctic temperature change (°C) over the past 60 years, 1949–2008, for winter (upper left), spring (upper right), summer (lower left) and autumn (lower right). Yellow, orange and red denote progressively stronger warming. Blue denotes cooling and white essentially no change of temperature.

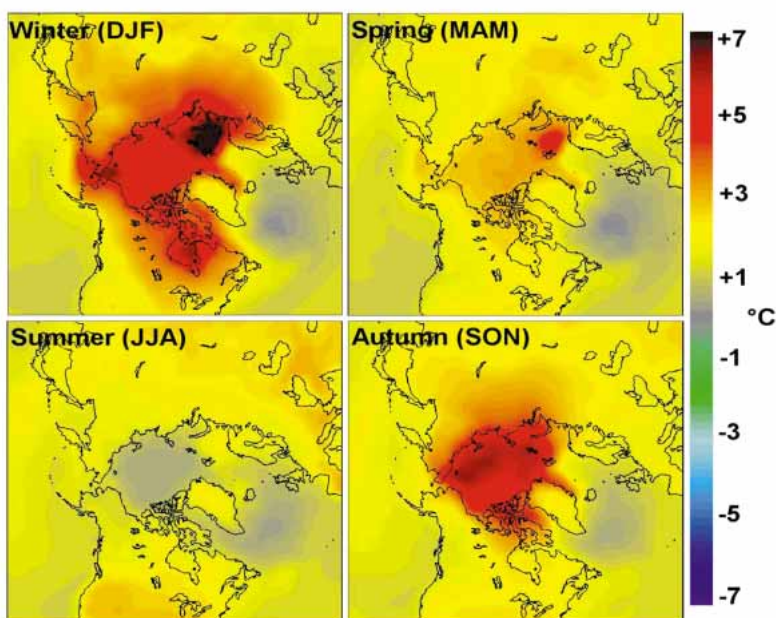


Figure 2. Projected changes of surface air temperature (°C) in 2070–2090 for each season based on simulations by climate models when run with a scenario (A1B) in which the rate of greenhouse gas increase is in the middle of the IPCC's range of plausible scenarios [2].

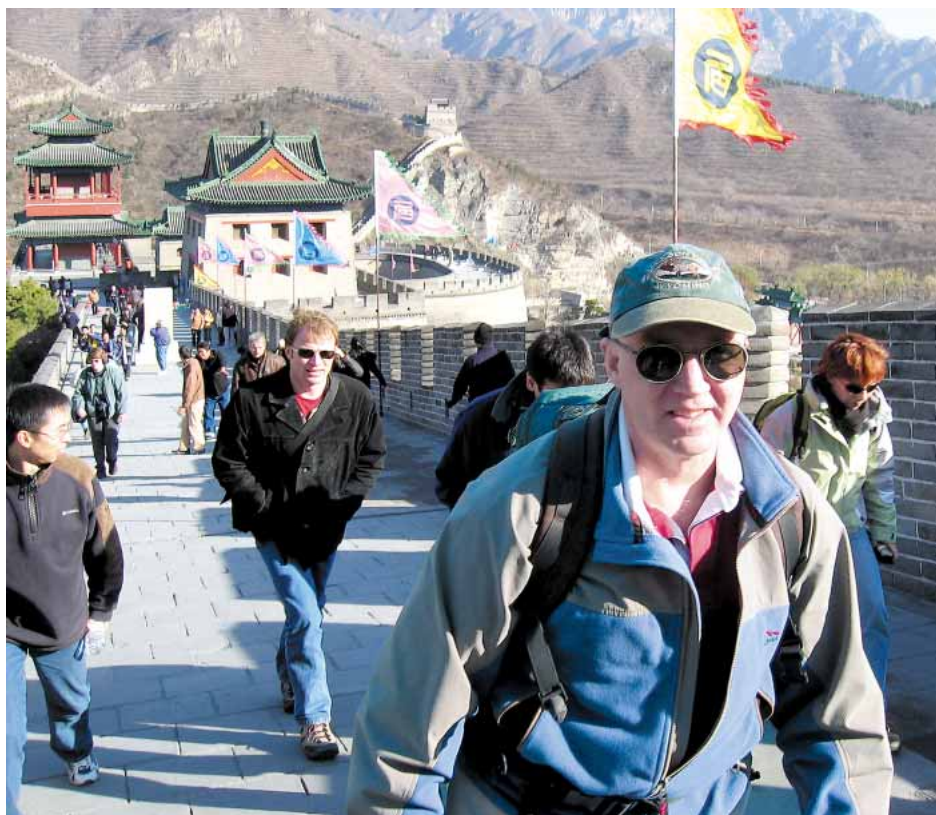
to develop means to anticipate shifts of the large-scale circulation, or at least the probabilities of important shifts during particular time periods. ■

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He has also worked in the Polar Research Board's committee to review NASA's Polar Geophysical Data Sets. Dr. McGuire is serving on several national-level science steering committees (SSCs) in the USA including the Carbon Cycle Science Steering Group of the US Climate Change Research Program, the SSC for the Study of Environmental Arctic Change (SEARCH), and the SSC for the Arctic Community-wide Hydrological Analysis and Monitoring Program. He has also been a member of several international committees concerned with global change science in northern high latitudes.

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Sensitivity of Arctic carbon in a changing climate

The Arctic has been warming rapidly in the past few decades. A key question is how that warming will affect the cycling of carbon (C) in the Arctic system. At present, the Arctic is a global sink for C. If that changes and the Arctic becomes a carbon source, global climate warming may speed up.

Here we define the Arctic as the Arctic Ocean plus the lands that drain into the Arctic or that have permafrost, excluding high-elevation areas farther south such as the Tibetan Plateau or Antarctica (Fig. 1). The Arctic contains vast amounts of carbon (Table 1).

Contemporary Arctic carbon stocks and fluxes

Atmospheric measurements indicate that the Arctic is a modest C sink with about 400 Tg (megatons) taken from the atmosphere

in an average year (Fig. 2). This amount can vary greatly from year to year. Studies of carbon dioxide (CO₂) flows at specific sites also indicate great variation from year to year.

Combining various studies and estimates for the terrestrial Arctic, it appears that land areas are a sink for approximately 300–600 Tg (C) yr⁻¹. This amount is 30–60% of the

Arctic Carbon Stocks	
Location	Amount, billions of tonnes
Land	
Soil	1400-1850
Living plants	60-70
Ocean	
Water column	
Dissolved inorganic carbon	310
Dissolved organic carbon	9
Sediments	9,4
Methane Hydrates	
Ocean	30-170
Land	2-65
Total	~1820-2485

Table 1. Estimates of current Arctic carbon stocks.

global estimate for the net C sink on land [1]. Lakes and rivers are a source of C to the atmosphere with 40–84 Tg (C) released each year.

Seawater in the Arctic appears to be a sink for 24–100 Tg (C) yr^{-1} . This accounts for 1–5% of the global estimate for the ocean C sink [1]. Carbon is also carried from land to rivers, from rivers to ocean, and from ocean to ocean. There is considerable uncertainty involved in most estimates of C transport, but river transport, ocean currents, and coastal erosion appear responsible for the largest amounts [1].

Recent atmospheric studies indicate that the Arctic is a source for 15–50 Tg of methane (CH_4) each year, or 3–9% of the global total net emissions from land and sea [1]. Site studies show a higher emission rate of 31–100 Tg (CH_4) yr^{-1} from land and fresh-water sources combined.

The role of small lakes in permafrost areas is greater than previously thought. These lakes are surrounded by carbon-rich soils laid down in the last ice age, now being released as the water thaws the frozen soil. Methane hydrates, which are ice-like solids in permafrost and below the floor of the ocean that contain a single molecule of CH_4 in a cage-like structure, do not appear to contribute much to Arctic emissions at present.

The response of Arctic carbon to climate change

In the next decade or two, the boreal forest may continue to grow, absorbing more carbon as trees become larger and the treeline expands northward. On the other hand, forest fires may increase in frequency and extent and insect outbreaks may kill more trees. Both of these processes would release carbon to the atmosphere. Which trend dominates the other depends in part on precipitation: dry conditions may reduce plant growth and lead to more fires.

It is also unclear whether increased CO_2 concentration in the atmosphere will stimulate plant growth in the Arctic because plant growth may be more limited by nitrogen availability in the soil than by atmospheric

Figure 2. Current state of the Arctic carbon cycle showing amounts of carbon stored in various environmental reservoirs (units: millions of tonnes C, or millions of tonnes CH_4 for methane and methane hydrate) and the net flux of compounds (units: millions of tonnes C per year, or millions of tonnes CH_4 per year for methane) that determine the movement of carbon between environmental compartments. Source: [7].

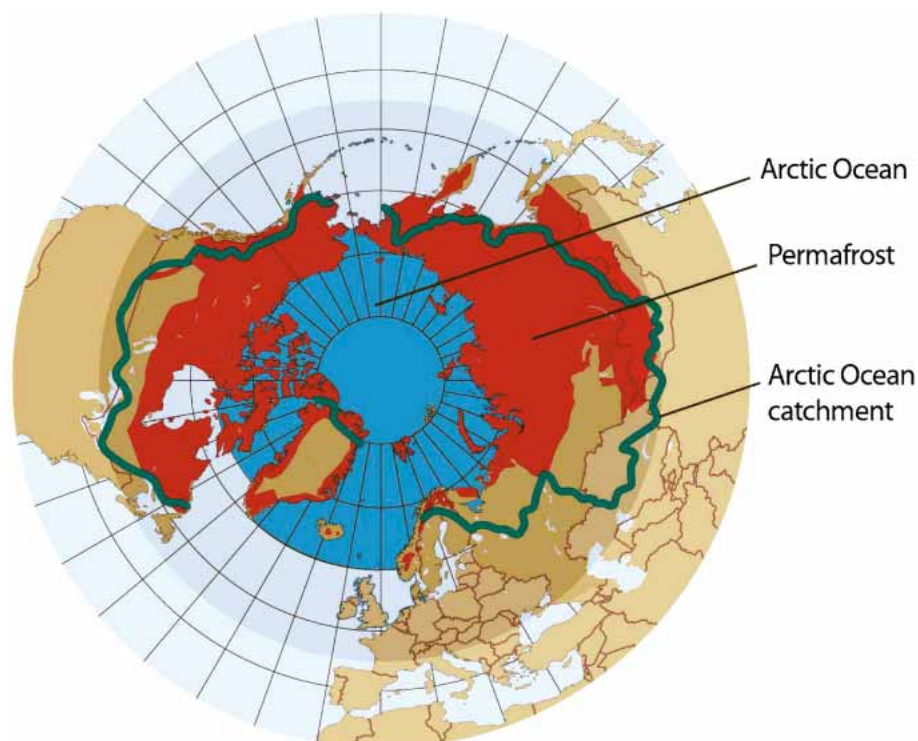
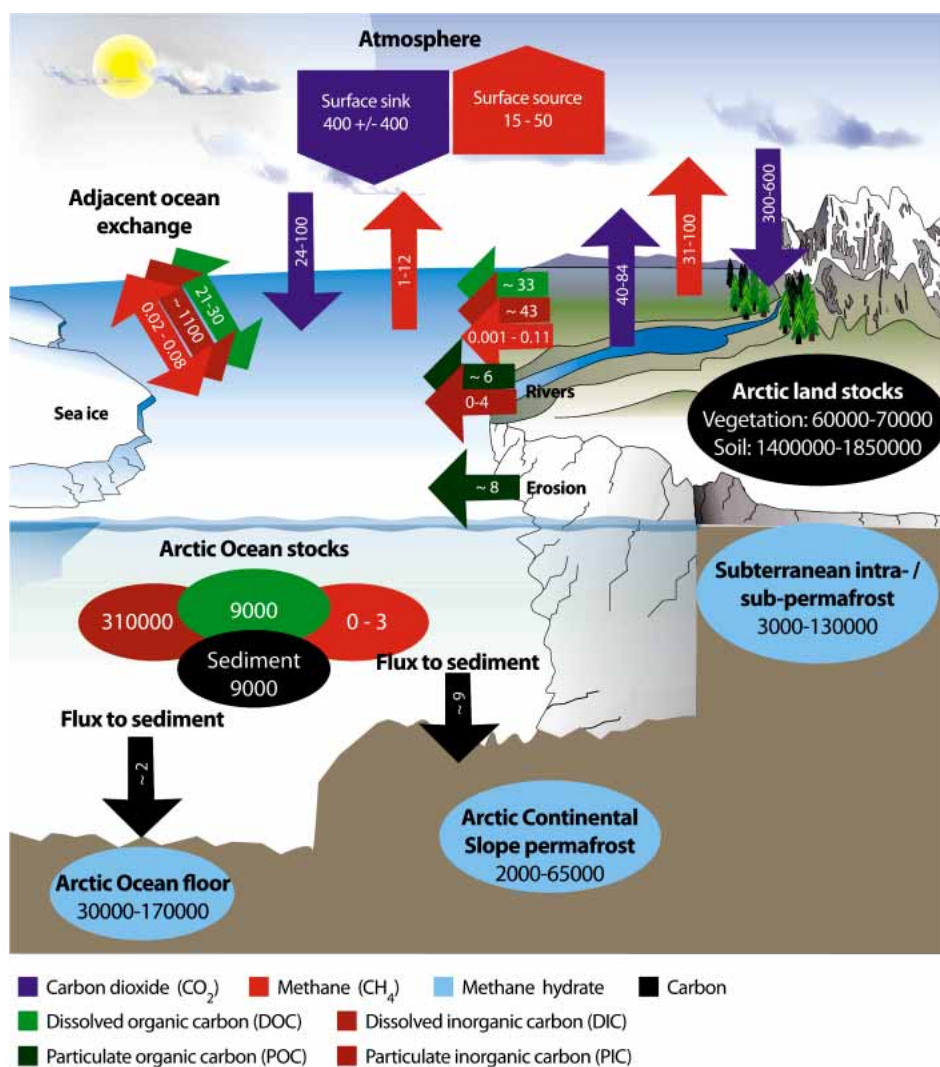


Figure 1. The region that we consider the Arctic. Source: [7].



CO₂ [2]. Although shrubs are moving into tundra areas, the movement of the actual treeline is very slow and will likely only have an effect on the C cycle of the Arctic over the course of several centuries.

Thawing of near-surface permafrost will mobilise C stored in the soil. Different studies show different patterns over time, but most agree that much carbon will become available by the end of this century [1]. Furthermore, fire in permafrost landscapes may accelerate thawing, a factor that has not been considered in studies to date.

Once permafrost has thawed, the release of C depends primarily on the wetness of the soil. Wetter soils will release more CH₄ but relatively less CO₂ than dry soils. Recent trends in the Arctic indicate that landscapes are typically drying as a result of climate change [3–5].

However, the changes in the Arctic carbon cycle appear to have only a modest influence on global climate. One study [6] projected a potential maximum release of 50 Pg (gigatons) of carbon from the Arctic terrestrial environment through this century, far lower than the 1500 Pg that are expected to be released even by low-end estimates of fossil fuel burning over the same period [6].

In the marine environment, too, feedbacks between climate and the C cycle can be both positive and negative. Reduced sea ice will allow more exchange of carbon from sea water to the atmosphere. It will also allow more light to reach the water, stimulating more plankton growth and thus uptake of carbon.

On the other hand, melting of ice will result in more freshwater in upper ocean layers, which can reduce biological activity and lead to less carbon being taken up by biota. These effects will act very differently in each season, making projections of the net change even more difficult. As the ocean warms, it can hold less dissolved CO₂. Furthermore, warmer water may lead to increased production of CO₂ and CH₄ through decomposition and other biological activity.

The discharge of water from land to sea increased in the Arctic throughout the 20th century, and is projected to continue to rise and perhaps accelerate during the 21st century. Increased water flow will likely be connected with increased C transport though the partitioning of carbon is difficult

to predict: one possibility is that carbon carried by rivers ends up stored in coastal sediments. Another possibility is that this carbon decomposes in the water column and is released as CO₂ and CH₄.

The release of CH₄ from gas hydrates currently locked in permafrost is likely to be a very slow process. Most hydrates are at considerable depth and so would not be affected in the short-term by near-surface thawing. Nonetheless, the fate of these gas hydrates remains largely uncertain in both the short- and long-term.

Further research should focus on sensitive elements of the carbon cycle

Current understanding of the Arctic C cycle is limited by considerable uncertainties, and integrated studies of regional carbon dynamics are necessary. Such studies should focus on understanding the mechanisms responsible for changes in C dynamics at the regional scale.

The resulting information should be incorporated into modelling efforts that connect carbon dynamics and climate. The studies should focus on sensitive parts of the system, for example areas experiencing major changes or thresholds such as permafrost loss or increased fire disturbance.

A major challenge for carbon modelling is upscaling: connecting fine-scale observational studies with the larger scales at which models describe the environment. Observational networks should be designed to capture regional variations and also to reveal the underlying processes that govern C dynamics at various scales. That information can be used to model the interactions among various parts of the C cycle. Observational studies should also focus on small- and large-scale processes so that both can be incorporated in models.

The improved understanding of C dynamics can be incorporated first in simpler models where the basic ideas can be tested. Then, more complex models that couple air, land, and sea can be developed or revised based on new and better understanding of the fundamental factors involved. This, in turn, will allow a more confident exploration of the relationships between climate change and carbon cycling in the Arctic. ■

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European Geosciences Union General Assembly 2–7 May 2010, Vienna, Austria

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iLEAPS is organising and co-sponsoring 12 sessions at EGU2010. Eight belong to a series of sessions called Biosphere-Atmosphere Interactions (BAI).

iLEAPS will organise a BAI dinner (with 2–3 prominent speakers giving perspective to the sessions) especially for the early-career scientists at EGU venue, night before the BAI sessions start. More information on the BAI dinner will be available shortly on iLEAPS web site (www.ileaps.org).

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Biosphere-Atmosphere Interaction (BAI) sessions co-sponsored by iLEAPS

BG2.2/AS4.16 From biogenic primary exchange to atmospheric fluxes of reactive trace gases

Co-conveners:

J. Kesselmeier, J. Rinne, J. P. Schnitzler

BG2.3/AS4.17 Trends and temporal variability in biogeochemical surface fluxes

Co-conveners:

P. Stoy, S. Luyssaert, A.D. Richardson

BG2.4/AS4.19 Novel methods of modelling terrestrial biogenic trace gas emissions and their effects on atmospheric chemistry and climate

Co-conveners:

A. Ameth, P. Friedlingstein, S. Zaehle

BG2.5/AS4.18 Improving measurements and models of soil respiration and its components

Co-conveners:

J. Subke, M. Khomik, M. Carbone, P. Stoy

BG2.9/AS4.20 Carbon and water cycles at multiple spatial and temporal scales

Co-conveners:

M. Reichstein, A.D. Richardson, C. Beer, D. Papale

CL1.21 How can we properly evaluate the role of land-use induced land-cover changes in the climate system?

Co-conveners:

N. de Noblet-Ducoudré, A. Pitman, G. Bonan

CL1.22 Feedbacks in the global Earth system in the past, present, and future

Co-conveners:

M. Claussen, V. Brovkin

HS6.9 Production, transport, and emission of trace gases from the vadose zone to the atmosphere

Co-conveners:

L. Weihermueller, M. Lamers

Other sessions co-sponsored by iLEAPS

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Implications from past to future climate

Co-conveners:

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BG2.1 Biotic interactions and biogeochemical processes

Co-conveners:

M. Bahn, R. Bardgett, M. Reichstein

AS2.1 Air-Land Interactions

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A. Ibrom, T. Foken

CL2.4 Shifting Seasons: Phenological evidence from observations, reconstructions, measurements and models (co-sponsored by PAGES & ILEAPS)

Co-conveners:

T. Rutishauser, A. Menzel, J. Weltzin

iLEAPS-related sessions

AS3.14 From gas to particles, new perspectives on organic compounds in the atmosphere

Co-conveners:

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We warmly welcome you to attend these sessions!





Scott Goetz works on the application of satellite imagery to analyses of environmental change, including monitoring and modelling the links between land-use change and disturbance (deforestation, urbanisation, wildfire etc.) with forest biomass, ecosystem productivity, biological diversity and water quality. Before joining the Woods Hole Research Center in 2003, he was a Research Faculty member at the University of Maryland College Park for 6 years, where he maintains an adjunct Associate Professor position. He was a contract research scientist at the NASA Goddard Space Flight Center from 1985 to 1995. He has authored more than 80 refereed journal publications and book chapters, and edited three special issues focussed on applications of satellite remote sensing.

Scott Goetz and Pieter Beck

Woods Hole Research Center, Falmouth, Massachusetts, USA

Recent changes in boreal and Arctic vegetation and their feedbacks to the climate system

The warming observed at high latitudes in the last 50 years exceeds the global average by as much as a factor 5, that is, 2–3°C in Alaska and Siberia versus 0.53°C global mean (from 2001–2005 relative to 1951–1980 baseline) [1, 2]. Such a dramatic change in climate influences the partitioning of energy throughout ecosystems, and results in changes in the output of energy from ecosystems back to the climate system, either amplifying the initial changes (positive feedback) or dampening them (negative feedback).

High-latitude warming is associated with greater growth and density of shrubs [3], latitudinal and elevational forest expansion [4], and a range of other vegetation responses [5]. The accumulation of biomass associated with increased productivity is a negative feedback in that it reflects a net removal of carbon dioxide (CO₂) from the atmosphere, but can also act as a positive

feedback by decreasing the amount of solar energy reflected back to space (albedo) and thus increasing the thermal absorption of energy at the surface.

In the Arctic environment, shrubs increase snow depth by trapping drifting snow which reduces the chance of the snow sublimating to vapour [6]. The greater snow depth delays spring snow melt and the associated decrease in albedo [7] and it promotes winter soil decomposition and CO₂ emissions by elevating winter soil temperatures [8].

Similarly, warmer summers result in deeper thawing of the active layer (the layer that thaws during summer) and mobilisation of previously frozen soil organic carbon, promoting greater microbial CO₂ respiration and anaerobic methane (CH₄) production, and increased evapotranspiration of water vapour—all powerful greenhouse gases [9]. In addition to the biotic responses and

feedbacks to climate at high latitudes, the degradation of permafrost increases heat fluxes to the atmosphere because a substantial thermal heat sink disappears.

Similar interactions and directional feedbacks occur in the response of high-latitude forest vegetation to warming, with potentially large changes in productivity, respiration, albedo-related radiative forcing, and the balance between them [10, 11].

Figure 1. Hypothesised effects of fire severity and drainage on post-fire successional trajectories in boreal forests of interior Alaska. NPP = Net Primary Production, SOC = Soil Organic Carbon. Predictions for carbon-energy trade-offs (the relationship between carbon assimilation as NPP and radiative forcing as albedo change) in young, intermediate-aged, and mature forest stands over approximately 100 years are indicated. Two possible successional trajectories are indicated for simplicity; in general stand types are highly variable and span the full range of broadleaf deciduous tree densities described by these two end members (from [11]).

Moreover, because warming and drying increases the frequency, intensity and the extent of fire disturbance [12], a multitude of legacy effects result from fire disturbance that influence the directionality and magnitude of feedbacks. For example, fires emit enormous quantities of CO₂ into the atmosphere in a short time, and influence regional climate in the following years via changes in spring and summer albedo [10], as well as rates of canopy conductance and associated evapotranspiration [13].

Increases in boreal forest fire disturbance thus have the potential of altering the global carbon cycle, not only because these areas store some 78 Pg of carbon in above-ground vegetation that can be rapidly transported to the atmosphere by fire, but also because the majority of the Earth's soil organic carbon stored at high latitudes (>1400 Pg) can be mobilised by fire as well as by the increased thawing and microbial decomposition that last for many years after a fire event [14].

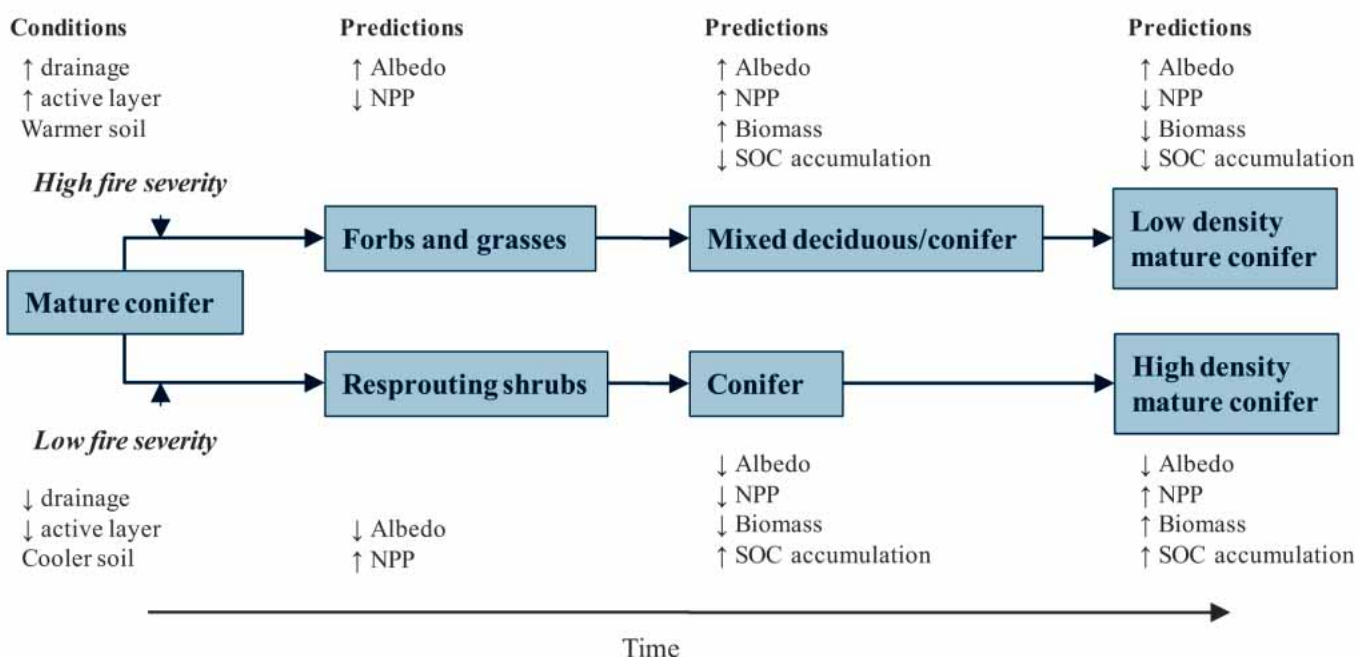
Thus, large carbon stores in high-latitude soil organic matter, resulting from the slow accumulation of peat under cold and wet conditions over millennia, are prone to more rapid decomposition and mobilisation in the warmer and drier conditions characteristic of climate change over the next few decades (the so called "carbon bomb") [15].

Pieter Beck is a vegetation ecologist who specialises in remote sensing and modelling of vegetation at high latitudes. His particular focus is on the effects of climate variability and change on the carbon dynamics, distribution, and composition of Arctic and boreal vegetation. His other research interests include the effects of landscape-scale environmental dynamics such as phenological patterns of vegetation on animal movement. He obtained his PhD from the University of Tromsø, Norway, and the Institute for Geo-Information Science and Earth Observation (ITC) in the Netherlands.

The trajectory of forest succession is also strongly influenced by fire, particularly fire severity. The classic paradigm of boreal forest succession following stand-replacing fire is of one that moves from early pioneer herbaceous and shrub species to an intermediate

phase with deciduous tree species dominating, and finally into a mature coniferous forest after 5 or 6 decades.

Changes in climate-induced fire severity, however, change this paradigm because more severe fires consume greater amounts





of soil organic matter (peat), which facilitates the establishment and persistence of deciduous trees (Fig. 1). There are negative climate feedbacks to the climate system associated with these changes (i.e. mitigating further warming), such as greater net productivity and shortwave albedo.

The greater albedo is most pronounced in winter when deciduous forest canopies are leafless and do not absorb as much incident solar radiation as a conifer canopy, but also because deciduous canopies do not impede the shortwave radiation reflected by snow back to space. Over large areas these

albedo changes have substantial consequences on energy balance and radiative forcing on climate, as the low winter albedo of coniferous boreal forest is replaced by the higher albedo of deciduous forest [10].

Other forcings, such as increased evapotranspiration (evaporation from surfaces and transpiration from vegetation) and reduced sensible heat flux (warming of air), are likely because deciduous trees have higher canopy conductance than coniferous trees [16]. Together, these negative feedbacks act to slowly offset, over long time scales, the larger short-term positive feedbacks asso-

ciated with direct carbon emissions from forest fire.

The responses and feedbacks described thus far are well understood in many ways, but the magnitude of the feedbacks under a changing climate and their implications and trade-offs are currently poorly constrained. For example, satellite observations of high-latitude vegetation indicated a ubiquitous 'greening' of areas north of 45°N between 1982 and 1991 [17]. A number of related studies, both observational and from model simulations, supported this view. More recently, however, satellite observational

Figure 2. Trends in satellite observations of vegetation photosynthetic activity derived from a 1982–2005 time series of Global Inventory Modeling and Mapping Studies (GIMMS) Advanced Very High Resolution Radiometer (AVHRR) vegetation indices, with significant positive trends shown in yellow and negative trends in brown. The trends map is overlaid on a 1-km resolution background mosaic of the Moderate Resolution Imaging Spectroradiometer (MODIS) imagery and ocean bathymetry derived from several data sources (see www.esri.com/data). From [11].

analyses of North America showed that this overall trend changed after 1990, with tundra continuing to green (increase in productivity) but boreal forest areas declining in productivity (“browning”), even excluding all areas burned in recent decades [18].

This decline, associated with a weakening of the high-northern-latitude carbon sink [19], has been attributed to drought, specifically higher vapour pressure deficit (difference between actual and maximum water vapour content in air) associated with warmer and drier air masses, which limits stomatal conductance (evaporation rate of water through pores in a leaf) and photosynthesis in boreal forests that are better adapted to cooler conditions [20]. The same trends and patterns were also documented across the circumpolar Arctic, with distinctly different responses in tundra versus boreal forest areas (Fig. 2).

The vegetation-climate feedbacks described above demonstrate the variety of mechanisms through which changes in terrestrial ecosystems can affect the climate system, resulting in a wide range of vegetation responses and trade-offs between positive and negative feedbacks. The contrasting recent trends in vegetation productivity at high latitudes, the variety of feedbacks related to vegetation succession after fire disturbance, and the interacting effects of vegetation and snow cover on radiative forcing via albedo illustrate how vegetation-climate feedbacks vary under a changing climate. The temporal dynamics of high-latitude vegetation feedbacks are therefore a critical aspect of understanding the future climate system, and the need to track high-latitude ecosystem change has never been greater. ■

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Present and future circumpolar Arctic terrestrial carbon cycling in a global perspective

Arctic tundra covers ~8% of the global land surface [1]. Peatlands are a ubiquitous feature of the tundra, with peatlands north of 45°N containing approximately half as much carbon (C) (~450 Pg) as exists within the atmosphere, and more carbon than in tropical forest biomass [2].

These massive carbon deposits are the legacy of peatlands, which acted as sinks of atmospheric carbon dioxide (CO₂) for millennia [3]. If climate change and changes in land use destabilise peatlands in the future, the result can be large CO₂ and methane (CH₄) fluxes to the atmosphere and large discharges of dissolved carbon to rivers [4, 5].

Exactly how high-latitude ecosystems respond to climate change will depend on the interactions between plant community composition and productivity, atmospheric CO₂ concentrations, water-table position, temperature, microbial activity and decomposition, nutrient status, and nutrient fluxes.

Among climatic regions, the high-latitudes are experiencing the most rapid

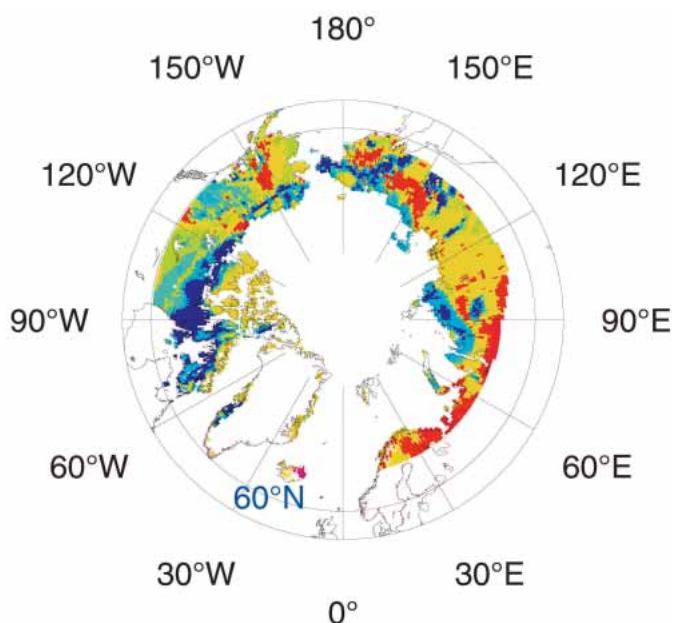


Figure 1. Simulated future changes in high-latitude carbon storage for one Terrestrial Biosphere Model (TBM) Lund-Potsdam-Jena (LPJ). LPJ is driven with future climate anomalies from the Hadley Centre

climate Model (HadCM3) using a future CO₂ concentration projection derived from the IPCC Special Report on Emissions Scenario (SRES B2) SRES B2 scenario; [11].



climate change [6] which may induce equally rapid changes in the carbon storage of the northern ecosystems. This is especially true for northern peatlands and Pleistocene (2.6 million to 12 000 years BP) organic carbon deposits underlain with melting permafrost [7, 8].

Recent & future trends in Arctic ecosystems

Remote sensing analyses indicate that tundra is greening in the Arctic because of an increase in photosynthetic activity leading to a greater net primary production (carbon absorbed to plants from the atmosphere) [9].

Modelling studies using Terrestrial Biosphere Models (TBM) generally suggest that the present-day Arctic acts as a small net sink for carbon [10]. As a result of the expected greater-than-average warming over the 21st century, the global TBMs predict that this sink will increase as enhanced vegetation production (absorption of C) exceeds increases in decomposition (release of C) (Fig. 1). This would reduce the amount of CO₂ in the atmosphere.

However, in response to rising soil temperatures, methane emissions are projected to increase over the next century [11]. The combined effect of higher CO₂ absorption and higher CH₄ release can be a net positive radiative forcing (*i.e.* climate warming), if the absorbed carbon returns to the atmosphere in the form of methane [12, 13].

The boreal treeline is also likely to expand northwards and add to the sink [10, 14, 15]. However, the timescales for this change are long—possibly centuries or more. Pollen records and tree mortality observations indicate previous warm periods in the mid-Holocene (about 6000 yrs BP) and medieval warm period (about AD 800–1300) experienced greater northward extent of boreal forest [16].

Any such future forest expansion will also affect the local climate through changes in surface albedo and the hydrological cycle leading to possible further amplification of local climate change [17–19].

The terrestrial carbon cycle may respond to climatic changes with significant delay [20]. This means that ecosystems may become committed to substantial damage or change long before any is observable (committed ecosystem change).

Similarly, changes in terrestrial carbon storage related to forest changes and climate-induced degradation of peat and permafrost may proceed for many decades after the climate has stabilised. When considering the implications of climate change, such committed ecosystem changes, in addition to realised changes, must be taken into account.

New joint research between the Met Office Hadley Centre and the University of Leeds under the EU project CarboNorth (<http://www.carbonorth.net>) is investigating this issue for high-latitude ecosystems with

Figure 2. Spatial heterogeneity across peatlands: a view of habitats at Cors Fochno, a temperate raised bog in W. Wales. Photo: Andrew Baird.

the coupled climate-carbon cycle model HadCM3LC.

Challenges in modelling circumpolar Arctic ecosystems

Key uncertainties in high-latitude ecosystem modelling as identified in [10] are:

- ❑ Representation of *plant functional types* by the current generation of regional models is largely limited to one or two types, which is insufficient to account for the diversity in tundra ecosystems. Correct representation of mosses would be particularly important. Mosses regulate the thermal and hydrologic dynamics of the tundra and thereby influence the carbon storage [21].
- ❑ Accounting for the intrinsic *spatial and temporal scales* of critical processes [22]. For example, the amount of water in soil can vary significantly at scales as small as metres [23] (Fig. 2). This variability in hydrological controls has a clear effect on carbon and nutrient dynamics. Scaling such heterogeneity to resolutions considered by regional models is a critical challenge [22].
- ❑ *Critical processes and feedbacks* currently unknown or not well represented by the models (permafrost dynamics,

nutrient cycling, fire, decomposition-soil moisture relations, etc. [24]). Permafrost, active-layer dynamics, and disturbance are crucial in shaping the Arctic landscape and its heterogeneity. An important consideration is the fate of soil organic carbon that is exposed by the thawing of permafrost. Also, an emerging issue in climate science is the need to model organic soils [25]. Fire is currently an important disturbance in Siberian tundra and may increase in regional extent, frequency, and severity under warmer climate conditions [10]. This may alter plant community structure.

Improvements in these areas will dramatically enhance our ability to model the response of Arctic ecosystems to future climate scenarios and assess the role of the Arctic in global climate change. ■

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Author assisting with snow depth measurements in ABACUS project, Abisko, Sweden 2007. Photo by P. Stoy, University of Edinburgh, UK.

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New frontiers, data practices, and directions in polar research

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(a)



(b)



Anja Engel received her PhD in Biological Oceanography from the University Kiel, Germany. After several post-doctoral years at the Alfred Wegener Institute for Polar and Marine Research (AWI, Germany), University of California at Santa Barbara (USA), and Stony Brook University (USA), she started a Helmholtz Young Investigators Group at the AWI. With her group, Anja investigates the mechanisms of biological carbon cycling and export in polar and coastal seas, and their sensitivity to global change, specifically to ocean acidification and warming.

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Future carbon cycling in the Arctic Ocean

According to recent climate model predictions, the Arctic is facing a century of severe environmental changes, progressing at a rate unprecedented during the last 55 million years. The temperature increase in the Arctic is about twice as fast as the global mean rate, yielding an average of $1\text{--}2^\circ\text{C y}^{-1}$ [1].

Scientists widely agree that global warming will strongly influence marine ecosystems, mainly because of effects on physical ocean dynamics, on the solubility of gases and mineral salts, and on biological process rates.

In the Arctic, warming additionally accelerates the melting of sea ice and Greenland's glaciers. Satellite data have revealed that the loss of Arctic sea ice has tripled over the last 10 years [2]. The loss of Arctic sea ice

is expected to enhance primary production, and thereby the biological fixation of carbon dioxide (CO_2) in the upper water column [3], but the net carbon balance of Arctic ecosystems in the future is still unclear.

Yet, global warming is not the sole CO_2 -related problem of the Anthropocene (late 18th century to present). Since the 18th century, increased uptake of CO_2 has induced a relative acidification of the surface ocean, shifting its slightly alkaline seawater pH from a pre-industrial average of 8.2 to the present 8.1.

If CO_2 emissions continue unrestricted, seawater pH is predicted to decline by another 0.5 until year 2300 [4]. In the Arctic Ocean, however, the uptake of anthropogenic CO_2 is expected to co-occur with higher freshwater input from the melting sea ice and from river discharge [1]. Whereas seawater can buffer acid addition because of its relatively high alkalinity, the alkalinity of freshwater is low or very low. Addition of freshwater therefore reduces alkalinity and hence the buffering capacity of the sea.

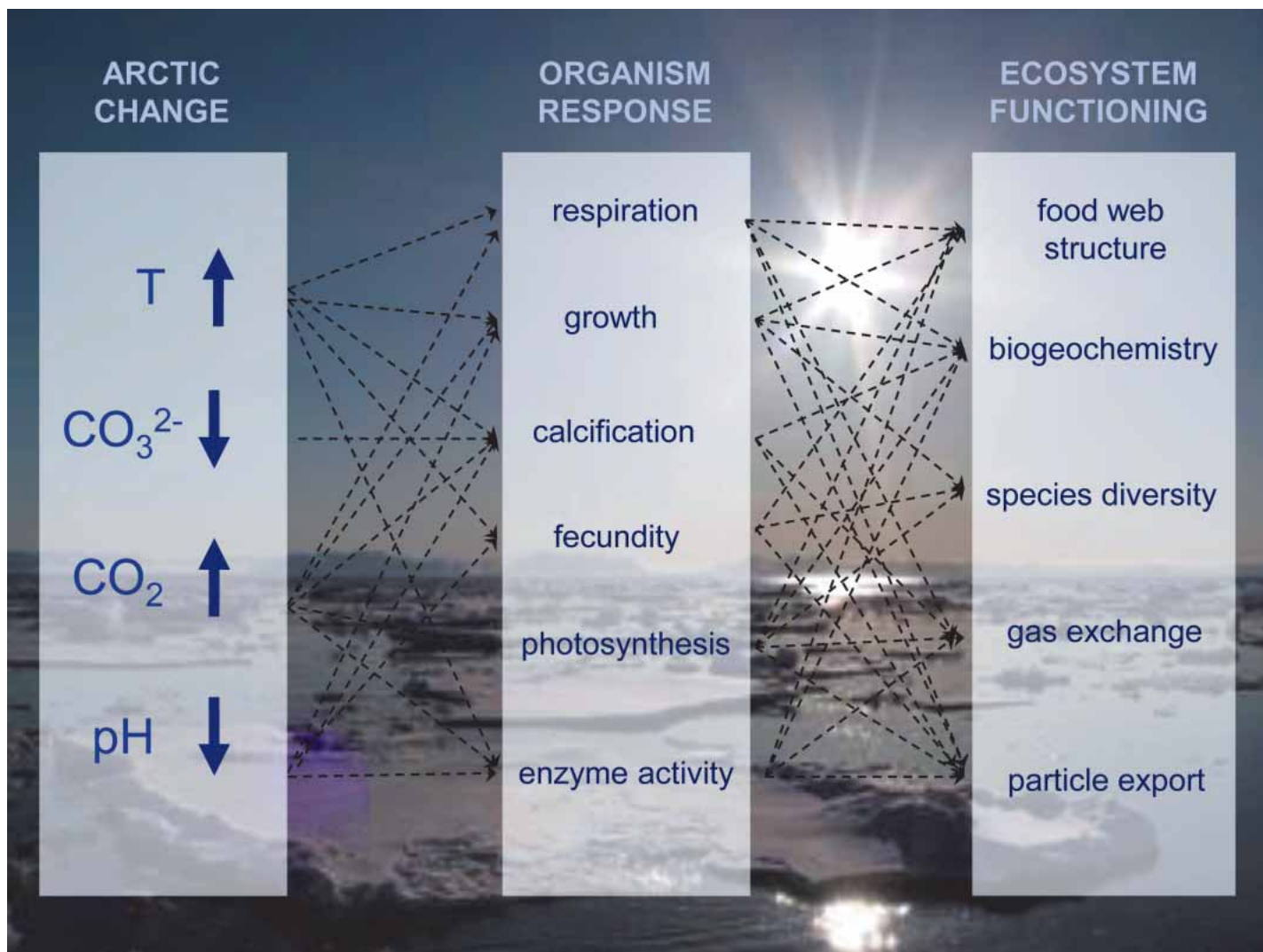
This will noticeably decrease pH within the next few decades [5].

As a consequence of acidification, the Arctic Ocean may become the first marine ecosystem where organisms such as cold water corals, swimming snails (pteropods) and other mollusk species will have to cope with the undersaturation of aragonite, a form of calcium carbonate that builds their skeleton material.

The aragonite shell of live pteropods dissolves in undersaturated conditions [6], jeopardizing the future survival of these species in the Arctic Ocean. Pteropods, such as *Limacina helicina* and *Clio pyramidata*, are key species of the Arctic food chain (Fig. 1), and their sedimentation contributes substantially to the vertical export of biologically fixed CO_2 from the surface to the deep ocean in polar seas [6].

The biologically mediated downward transport (vertical export) of carbon in the ocean, also known as the *biological carbon pump* is an important process within the global carbon cycle because it increases the

Figure 1. (a) *Limacina helicina* and (b) *Clio pyramidata*, two mollusk species living in the Arctic Ocean, are expected to suffer from seawater acidification. Organisms in (a) sampled with moored sediment traps in AWI-HAUSGARTEN, photo (a) by B. Pauls, AWI. Photo (b) by I. Arndt, AWI.



oceanic CO_2 sink: CO_2 is removed from the ocean's surface and thereby it escapes direct exchange with the atmosphere for a prolonged time. The resulting undersaturation of surface waters enhances the physical uptake of CO_2 and finally leads to a net reduction of atmospheric CO_2 .

Given these fundamental environmental changes, the future biological carbon cycling in the Arctic Ocean is difficult to predict. The sensitivity of Arctic plankton to variations in temperature, sea-ice extent, CO_2 and pH, or to high loads of mineral soils is not well known. The influence on the ecosystem functioning is even harder to predict, as combined changes in the organisms' chemical and physical environment may amplify or dampen one another, and will likely induce cascading ecological effects (Fig. 2).

Experimental perturbation studies that simulate the effects of global change on individual plankton species or on selected communities provide a clue of what to

Figure 2. Exemplified scheme of direct effects and ecological consequences of physical and chemical environmental changes, potentially impacting future carbon cycling in the Arctic Ocean. Photo: E. Halbroth, AWI.

expect in the future. Experimental findings suggest that the biological uptake of CO_2 in the surface ocean and the export of carbon-rich material to deeper water may increase in the future [7–8]. This has been attributed to the increasing production of transparent exopolymer particles (TEP) under high CO_2 (Fig. 3) [9–11]. TEP are carbohydrate-rich gels that primarily originate from phytoplankton cells. Because of their high stickiness, TEP enhance the formation of large and rapidly sinking particle aggregates.

On the other hand, TEP production represents a supply of biodegradable, carbon-rich organic matter. Marine bacteria in particular may benefit from this additional food source [13]: their carbon demand will likely increase in the future because of

higher metabolic activity at higher temperatures [14, 15]. If bacteria degrade a significant amount of the additional TEP before it can aggregate with particles (such as cells) and sink out of the surface ocean, this additional amount of CO_2 fixed in TEP would be either transferred into non-sinking dissolved organic material (DOM) or respired and released back to the atmosphere. In this respect, bacteria counteract the hypothesised TEP export pump.

Regional changes in the future Arctic carbon cycling are likely if key species disappear. The basis of the Arctic food web consists of unicellular algae, predominantly the silicified diatoms that thrive at the ice-seawater interface. These species feed the cold-adapted food web ranging from microscopically small animals to polar bears. Loss of the sea-ice habitat will therefore severely affect the associated community, potentially giving rise to the northward propagation of more boreal species.

Estimating future carbon cycling in Arctic ecosystems is particularly challenging because even present-day dynamics are still poorly understood. Yet, the pristine polar seas are unique indicators for global change and, as such, increasingly attract young scientists. In the framework of the newly launched European Project on Ocean Acidification (EPOCA, www.epoca-project.eu), CO₂ perturbation studies will be carried out at Svalbard to better understand the influence of Arctic Ocean acidification on biological processes within the water column and at the seafloor, including carbon cycling.

Those studies, together with data from long-term observatories such as the AWI-HAUSGARTEN, a key site of the European Network of Excellence ESONET (European Seas Observatory Network) east of Svalbard, will provide important data to advance Arctic ecosystem modelling and to improve our ability to predict how the poles and the oceans will respond to future climate change. ■

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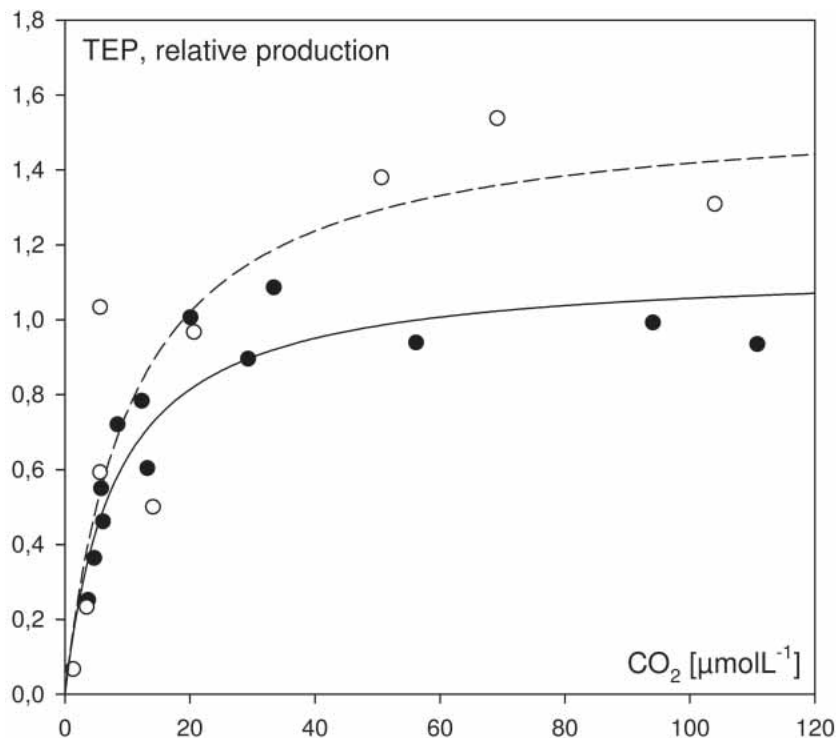


Figure 3. Increase of the relative production of Transparent Exopolymer Particles (TEP) as a function of CO₂ concentration during perturbation experiments with a natural plankton community (closed circles) and with a culture of the marine diatom *Thalassiosira weissflogii* (open circles). Data from [9] and [16].

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Presence and absence of permafrost – implications for atmospheric exchange of CO₂ and CH₄

Permafrost, soil that stays frozen for two or more years continuously, is a hot topic that has attracted a lot of attention in both the scientific and popular literature in recent years. Permafrost underlies 25% of the land areas in the Northern Hemisphere. With climate warming particularly pronounced at high northern latitudes, many questions arise regarding what may happen to ecosystems and their functioning in the areas when permafrost thaws.

In areas with infrastructure such as towns in northern Siberia or oil and gas pipelines through areas underlain by permafrost, the thawing represents a risk with serious and potentially extremely expensive consequences. However, thawing permafrost may also have global implications through changes in the greenhouse gas emissions from natural ecosystems.

Permafrost areas in the circumpolar North are estimated to hold more than 1600 Gt of organic carbon (C) including almost

300 Gt in the form of peat [1, 2]. The potential for future emissions of carbon dioxide (CO₂) and peat-derived methane (CH₄) is, therefore, probably greater in permafrost areas than anywhere else in the world.

Despite the huge carbon release potential of these areas, around-the-year monitoring of atmospheric greenhouse gas exchange is still rare and continuous flux measurements of CO₂ are limited to a handful of sites. Continuous monitoring of CH₄ fluxes is even rarer; the number of operational sites is less than five. Our empirically based understanding of what permafrost does to the dynamics and interannual variability in atmospheric (and dissolved run-off) fluxes of organic carbon is therefore still very poor.

Recent studies have discovered basic features of how these ecosystems are functioning with and without permafrost. Old, organic, previously frozen carbon in a central Alaskan site was released into the

atmosphere as the permafrost thawed [3] and in Siberian thaw lakes methane formed on recently thawed old organic deposits [4].

The interannual and across-site variability of CO₂ exchange in continuous permafrost ecosystems depends primarily on growing-season dynamics and moisture conditions. Growing-season rates of CO₂ uptake by these ecosystems have been shown in several studies to be closely related to the timing of snow melt, with earlier snowmelt resulting in greater uptake of atmospheric CO₂ [5, 6].

In addition, the annual C budget is largely controlled by the losses during the shoulder (snow melt/soil thaw and senescence/soil freeze) and winter seasons [7]. This more complex influence on the annual budgets becomes more important when moving out of permafrost regions and into climatically milder off-season conditions.

We have documented changes in permafrost dynamics and their effects on



Figure 1. The high-Arctic site in Zackenberg, NE Greenland, an area underlain by continuous permafrost. The automatic chambers were used for the studies of methane emission dynamics during freeze-in [11]. Local inhabitants, the musk oxen, are present in the background. Photo: C. Sigsgaard.

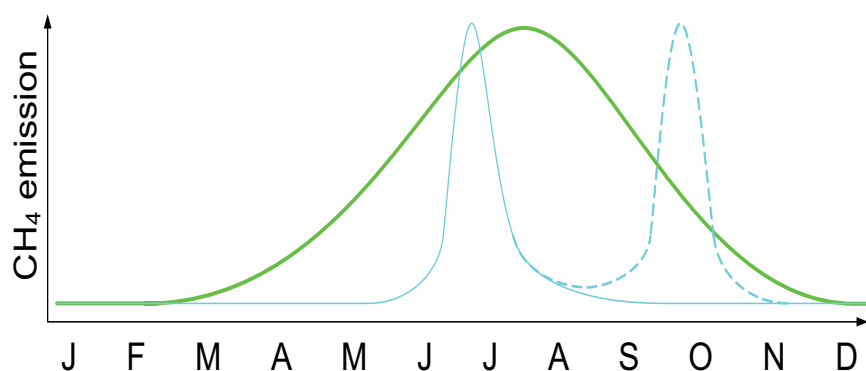


Figure 2. Schematic illustration of the seasonal dynamics of emissions as observed in the high Arctic in Zackenberg (light blue) and subarctic Sweden (green). The difference in the length of the growing season and the special freeze-in methane burst in the autumn in Zackenberg are evident (based on data from [10, 11]).

ecosystems and greenhouse gas emissions in northern Sweden [7–9]. These subarctic areas lie within the zone of discontinuous permafrost where permanent ice underlies 50–90% of the ground. Here, and even more so in the zone of sporadic permafrost (<50%), the thawing permafrost generally leads to wetter hydrological conditions and subsequently greater greenhouse gas emissions at the landscape scale. The seasonal and interannual pattern in these sites are rather predictable and the emissions rather stable from year to year [10].

The situation is different in areas with continuous permafrost. At our high-Arctic measurement site in NE Greenland (Fig. 1),

we observed some surprising and interesting autumn emission dynamics. These findings [11] showed a second seasonal peak of CH_4 emissions during the freeze-in (Fig. 2), a distinct feature not previously observed and not seen in the subarctic studies. A likely reason is that no earlier flux studies in continuous permafrost regions have extended into the frozen season.

After further investigation together with atmospheric scientists, we tentatively concluded that this autumn peak could well be a feature typical for permafrost areas. In fact, as it turns out it helps to explain the observed seasonal pattern of atmospheric methane concentrations during the autumn

that has been known for years but not fully understood [11]. This pattern includes an autumn hump in the seasonal cycle of atmospheric methane that is particularly pronounced at high-latitude stations. It may well be that the observations [11] provide at least a partial explanation for this distinct feature in the atmospheric records.

We believe that the mechanism behind the freeze-in methane emissions in continuous permafrost areas is a release of methane from the subsurface pool accumulated over the growing season (Fig. 3). The methane is present mainly in gaseous form in entrapped gas bubbles below the water table level.

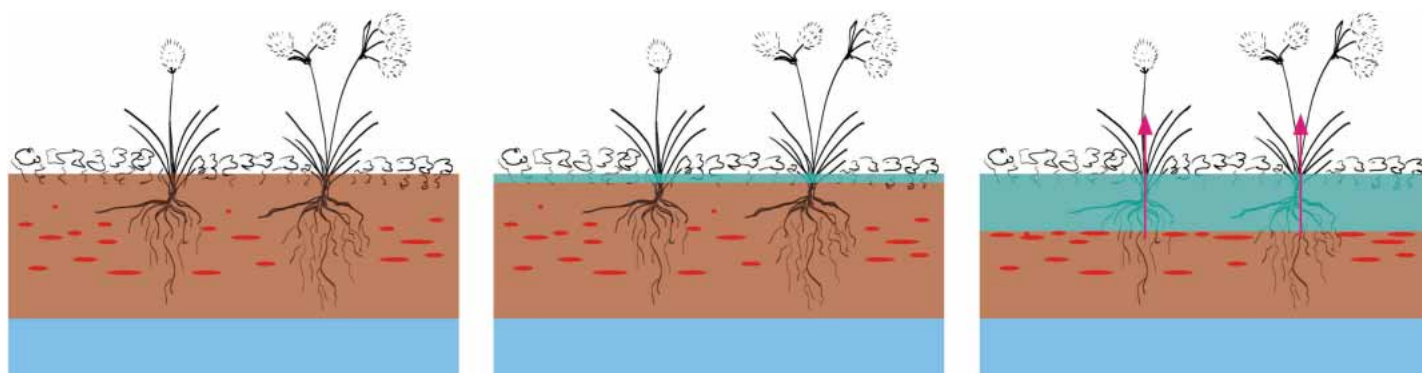


Figure 3. The hypothesised mechanism behind the freeze-in burst of methane in continuous-permafrost environments. As the ground freezes primarily from the surface down, pressure builds up in the unfrozen zone below and the accumulated gas in the soil is squeezed out into the atmosphere through physical cracks and pores that form in place of senesced vascular plants.

The volume of the gas phase in the peat beneath the water table can be significant (from 0 to 19% [12]) and the volumetric percentage of methane in this gas can be more than 50% [12]. When the soil starts to freeze at the surface, it becomes a gas-proof layer that gradually propagates downwards as the freezing continues. The permafrost below, in turn, works as a gas-proof bottom preventing the gas from migrating deeper down. As a consequence, the gas is trapped in the soil between these two gas-proof layers.

Because the density of ice is lower than that of water, the freezing process increases the volume of the freezing zone and raises the pressure in the unfrozen layer below. As a result, the gas with high methane content bursts into the atmosphere through suitable channels in the frozen active layer. We suggest these channels may be residuals of vascular plant tissues or simply cracks in the frozen upper soil layer [11].

The mechanism described above should not only affect CH_4 , but also CO_2 stored in the peat. Indeed, we also found a late-season CO_2 peak accompanying the one of CH_4 . However, for CO_2 the magnitude is too small to seriously alter the annual carbon balance.

Within the geographical margins of the permafrost zone is Abisko, the intensively studied region of northern Sweden where permafrost has been monitored for decades. The active layer has become thicker during the last three decades. In nine mires along a 100-km-long transect, the trend has been similar and in some mires the permafrost has even disappeared completely [13]. This trend has been observed also in larger-scale modelling of the whole of permafrost (palsa) mires in northern Scandinavia [14] and in observations in North America [15, 16].

On the whole, this uniform trend towards transformation of permafrost landscapes calls for an understanding of ecosystem fluxes both where the permafrost is still present and where it has disappeared. From the few data we have, our understand-

ing is that ecosystems in areas with and without permafrost differ significantly in their functioning. We need more continuous measurements both to document ongoing changes and to gain a process understanding necessary for modelling both large-scale transitions in permafrost ecosystems and their interactions with climate. ■

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Project participants at a recent workshop in Boulder, Colorado. Upper row left to right: Patrick Boylan, Brian Seok, Brie VanDam, Louisa Kramer, Laurens Ganzeveld; middle row: Stephen Goodwin, Richard Honrath, Robert Millsbaugh, Claudia Toro, Amy Cox, Jenny Thomas, Detlev Helmig; front: Jacques Hueber. *Our colleague and lead principal investigator of this project, Richard Honrath, tragically died in an accident this spring. We sorely miss Richard and his inspiring ideas and contributions to this research. This work is dedicated to his memory.*

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Until recently, snow-covered surfaces were believed to be nearly inert with respect to the exchange of chemical compounds, as atmospheric trace gases generally show low surface deposition rates. However, newer research dating back to some ground-breaking discoveries in 1999 has yielded increasing evidence that sunlit snowpacks are active photochemical environments that can significantly alter surface exchange and the composition of the overlying atmosphere [1].

Snowpack processes affect atmospheric ozone (O_3) in two ways:

1. destruction within the snowpack;
2. photochemically mediated release of precursors that can cause O_3 production above the surface.

O_3 production during stable and shallow boundary layer conditions above the snow has been reported in several studies. This phenomenon might explain observed upward fluxes of O_3 over snow reflected by

negative “deposition velocities” (apparent O_3 emission) that have been described in the literature [2, 3].

Destruction of O_3 in air withdrawn from a polar snowpack was first reported at Summit, Greenland, in 2000 [4]. Those observations demonstrated a dependence of the ozone destruction on sunlight intensity, and a negative correlation with nitrogen oxides ($NO + NO_2 = NO_x$). Follow-up studies with more in-depth observations at Summit, the South Pole, Niwot Ridge (Colorado), and

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Alert (Canada) confirmed these first results and further elucidated the dynamics of ozone loss in snow at those locations [5].

Observations conducted at Summit [6] showed that O_3 levels in the snow decrease with depth, and that the magnitude of the ozone reduction increased with sunlight intensity, indicating the role of a photochemically modulated process in destroying O_3 .

The mechanism driving this in-snow O_3 destruction is not yet fully understood. The O_3 destruction appears to be closely related to production of NO_x , which is associated to the photolysis of deposited nitrate. In regions with seasonal snow cover over soil, biogeochemical processes can dramatically alter the composition of the air trapped inside the snowpack, and this build-up of reactants in the snowpack can greatly affect the ozone chemistry in the snow and its O_3 surface fluxes.

Besides these chemical processes occurring in the snow, atmosphere-snowpack air exchange also depends on diffusion, convection, and (most importantly) wind pumping, driven by pressure fluctuations as wind flows over the snow surface [7]. The result is a loss of O_3 from the near-surface atmosphere, with the loss increasing as wind speed and insolation increase.

The snowpack photochemistry also results in the release of NO_x and hydrogen oxides (HO_x) precursors such as hydrogen peroxide, formaldehyde, and nitrous acid ($HONO$). NO_x catalyzes photochemical formation of O_3 in the above-snow atmosphere. In a modelling study for conditions at Summit, we estimated net O_3 summertime production rates of $\sim 2\text{--}3$ ppbv day^{-1} [8]. Even higher production rates up to 7 ppbv day^{-1} occur at South Pole causing a doubling of surface ozone when stable boundary layer conditions are sustained over periods of several days [9].

As a result of the simultaneous in-snow destruction and above-surface production, the net influence of snowpack processes

upon the tropospheric O_3 budget over snow is rather complex. In particular, this combination of uptake by the snowpack and chemical production above it results in a flux divergence (change of magnitude or even of the sign of the flux) in the near-surface region.

Consequently, above-snow O_3 flux measurements must be interpreted very carefully. Attaining a better understanding of this flux divergence requires measurement of gradients and fluxes at multiple heights and environmental conditions. Similar to ozone, concentrations of NO_x and radical precursors (and, as a result, the rate of O_3 production) are expected to vary vertically because of the competing effects of deposition to the surface, snowpack emission, and photochemistry in the atmosphere.

The limited experimental observations available to date indicate that snowpack-atmosphere interactions and chemistry above the snow are of sufficient magnitude to affect tropospheric O_3 levels over the large polar regions [10]. Climate change in the Arctic is anticipated to be more pronounced than in any other area on Earth [11]. The snow and ice environments are rapidly responding to the Arctic warming, and future trends in snow cover, snow depth, sea ice, and permafrost extent are expected to be significant [11].

Given the dependence of ozone fluxes on surface snow conditions, the anticipated changes in these variables are likely to affect air-snow exchange processes, tropospheric ozone, and chemistry-climate feedbacks in polar regions.

These questions are at the centre of our current study "Collaborative research: A synthesis of existing and new observations of air-snowpack exchanges to assess the Arctic tropospheric ozone budget", a project funded by US NSF's Arctic System Science Program. The objective is to develop, implement, and evaluate a representation of the key processes governing the influence of surface exchange above snow on tropospheric ozone simulated by chemistry-climate models.

Activities include

1. A review and synthesis of results from prior field studies relevant to O_3 and NO_x exchange fluxes;
2. New field studies to fill key knowledge gaps, especially those related to the dependence of vertical O_3 fluxes on height above snow and sub-snow surface type;

3. Incorporating parameterisations of snowpack and sub-snow processes into a single column model (SCM) version of a chemistry-climate model [12];

4. Applying that model to assess its ability to simulate the range of observations with a minimum of adjustable parameters, and

5. Providing a first estimate of the total influence of current snow- and ice-cover upon tropospheric O_3 in subarctic and Arctic regions.

The project started in 2008 with snowpack and above-surface O_3 and NO_x concentration gradient and flux measurements at Summit which has a year-round snowpack typical of the polar regions. A particular emphasis of this experiment is to add to the previous shorter studies a year-round record to better assess the seasonal dynamics of snow chemistry.

Another objective of the current activity at Summit is to make concurrent flux gradient and eddy covariance measurements at multiple heights. These observations are a prerequisite for assessing flux divergence of O_3 at the Arctic snow-air interface.

Challenges for these year-round flux measurements under the harsh weather conditions are plentiful and we had to develop a series of new experimental platforms. The new flux facility at Summit (Fig. 1) encompasses a 10-m flux tower for gradient measurements at multiple heights. To minimise disturbance to atmospheric surface flow, a $\sim 40\text{-m}^2$ laboratory housing the analytical instrumentation was placed ~ 10 m below the snow surface, accessible by a much smaller vestibule and a set of stairs leading to this underground laboratory.

A manifold with multiple inlets allows sampling of air from within the snowpack at 30-cm intervals down to the depth of about 2.5 m. Above ground, an inlet mounted to a remotely controllable, movable elevator facilitates the highly sensitive and continuous sampling of concentration gradients within the first two metres above the snow.

Three sonic anemometers are equipped with automated heaters that are activated when automated data quality control scripts detect riming or snow accumulation on sensors. Custom-built chemiluminescence analysers for measurements of O_3 and NO_x were tailored to achieve the high sensitivity necessary for the gradient and eddy covariance flux experiments under these polar conditions.



Figure 1. Experimental flux facility at Summit for the snow-atmosphere gas exchange experiment: a) the 10-m tall flux tower and at the right the entrance of the research trench; b) the 10-m tall flux tower; c) the 8-inlet snowpack gas sampling manifold. The snow tower has paired inlets spaced at 30-cm depth intervals. At the time when this picture was taken, five of the inlets were covered by snow.

These new measurements have already provided a wealth of observations for contrasting meteorological and chemical regimes and will be used to further develop and evaluate the air-snow chemical exchange models implemented in the SCM. Currently, we are conducting an extensive evaluation of the SCM's simulations of micro- and boundary layer meteorology since these mainly control the production, destruction and transport of chemical compounds.

For example, comparison of the simulated and observed surface solar radiation, relevant to the energy balance as well as photolysis rates, for 14–20 April 2009 (Fig. 2), indicates that the SCM simulates quite well the observed radiation.

The SCM-simulated O_3 mixing ratio for the same week over Summit up to 1000-m altitude is shown in Fig. 3. The SCM, which simulates online all the meteorological, hydrological and chemical processes in the air column but excludes the role of advection, was forced towards the ECMWF (European Centre for Medium Weather Forecast) re-analyses data (the so-called nudging of the model) to consider the role of advection of momentum, heat and moisture [13]. This also explains the large variability in the simulated boundary layer depth, indicated by the black-dotted line (without nudging one would simulate rather constant day-to-day meteorology). On 17 April, the boundary layer becomes much higher than before which indicates a strong increase in vertical transport. This also results in the enhanced downward transport of O_3 to the surface (red colour).

The timing of this simulated increase in surface layer O_3 correlated quite well with the observed increase in O_3 mixing ratio within the snowpack (Fig. 4 top)—a convincing example of how ozone and meteorological conditions above the surface influence air inside the snow.

On the other hand, during the same week, NO was observable only in the upper ~50 cm of the snow, with maxima occurring in the noon-early afternoon hours. In contrast, NO_2 was present much deeper and, in contrast to NO , the maxima occur at night. The differences in the observed patterns of O_3 , NO (Fig. 4 middle) and NO_2 (Fig. 4 bottom) point towards rather different mechanisms governing the formation and destruction of these three gases.

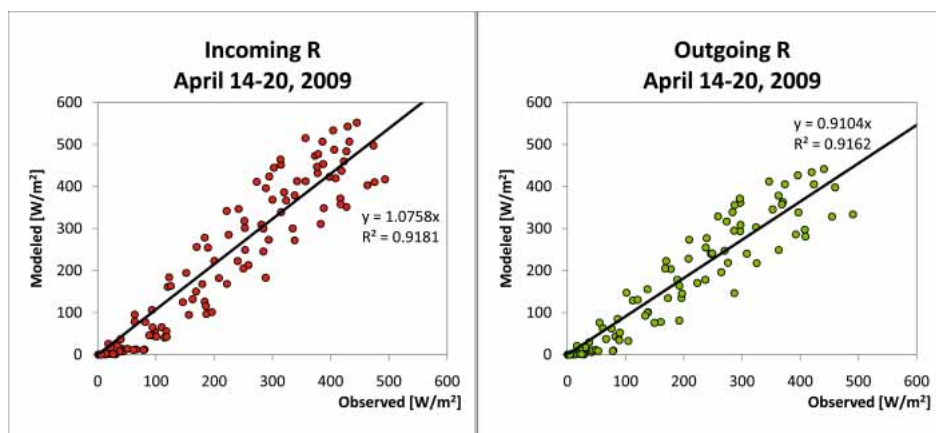


Figure 2. Comparison of simulated and observed a) incoming and b) outgoing surface solar radiation, Summit, 14–20 April, 2009.

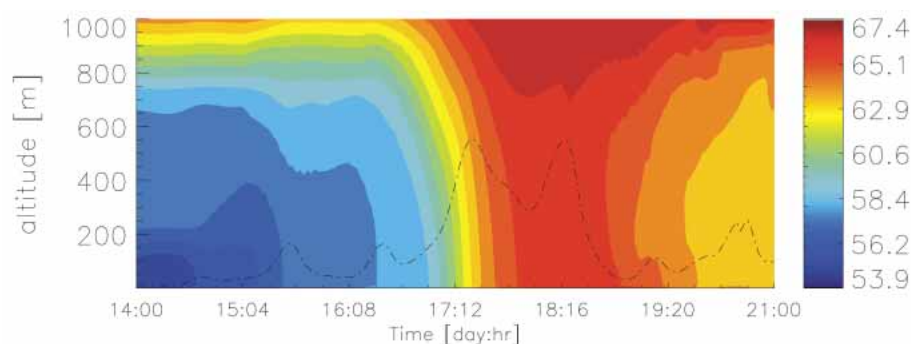


Figure 3. SCM-simulated ozone mixing ratio up to 1000-m height above the surface at Summit, 14–20 April, 2009. Time is shown as day:hr. During this week, an interesting ozone event, resulting in a strong increase of ozone was encountered. This transport event was associated with a rapid (simu-

lated) increase of the mixed layer from ~100 m to >500 m (dotted line, April 16–17). In addition to supporting observations within the snowpack (Fig. 4), previous balloon observations showed strong downward transport of ozone-rich air at Summit during spring-summer [14].

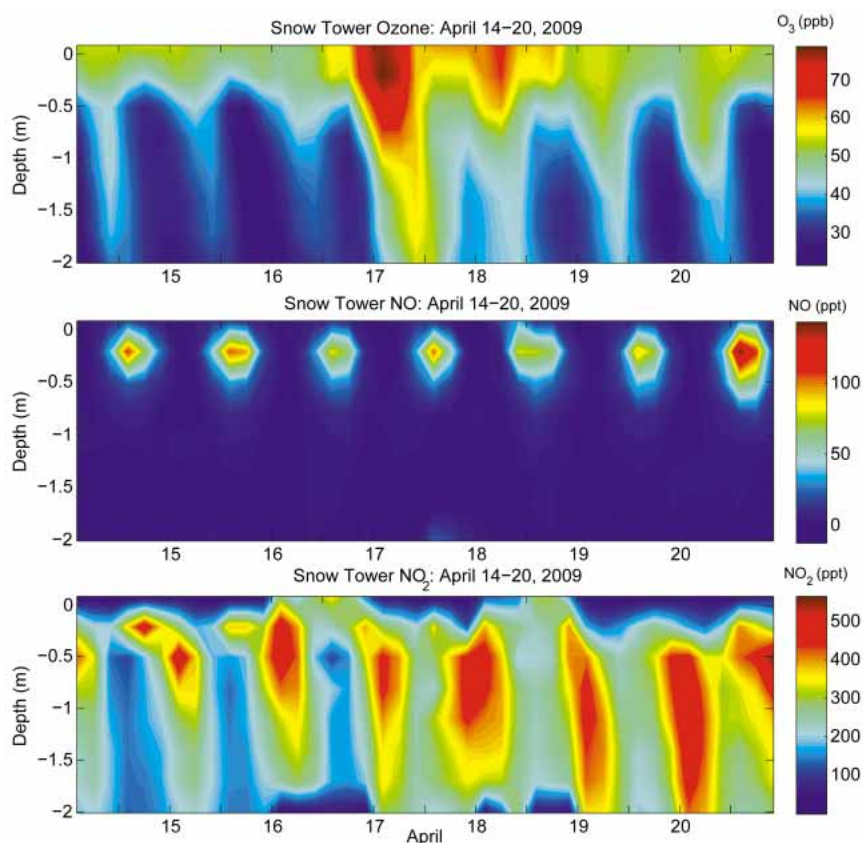


Figure 4. Chemical observations from the snowtower (Fig. 1c) during the same period as in Fig. 3. Top panel: ozone mixing ratio within the snow pack. The transport event described in Fig. 3 (an increase in O_3 of ~30 ppbv) affected the ozone concentration down to 2 m below the surface, with

ozone-rich air penetrating the snow at a rate of ~0.3 m h⁻¹. Middle panel: NO mixing ratio; bottom panel: NO₂ mixing ratio. Neither NO nor NO₂ appeared to be largely affected by the influx of ozone into the snow.

This experiment is still ongoing; the year-round experimental record, together with model analyses, will be used for an in-depth chemical and transport interpretation of these O_3 -NO_x dynamics.

This research has made major strides towards elucidating the connections between chemical and mixing conditions above and below the snow surface. Interactions be-

tween the snow and the atmosphere are clearly dynamical processes that govern the chemical behaviour of the atmosphere above the snow. Consequently, much needs to be learned about the controls and connections and their appropriate consideration in surface exchange processes and atmospheric models. ■

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Global change research networking: the role of IGBP National Committees

Global environmental-change research can no longer be conducted as a purely curiosity-driven exercise and it can no longer be tackled by a single nation in isolation: the challenges are too great, the costs too high, the need for better understanding too urgent. Those most affected are often the poorest. How can nations with small research budgets influence the global research agenda to tackle the challenges most pressing to them? A highly effective way is through the national committees of the big international research programs like IGBP (International Geosphere-Biosphere Programme).

I joined IGBP in May 2009. I came from the UK's Natural Environment Research Council (NERC) where I was head of publications. NERC funds several international project offices including IGBP's GLOBEC (Global Ocean Ecosystem Dynamics) and a node of the Global Land Project so I thought I pretty much knew all there was to know about IGBP and the other three major environmental-change research programs, the International Human Dimensions Programme (IHDP), the World Climate Research Programme (WCRP) and DIVERSITAS, the global program on diversity. I knew they ran maybe five or ten major international

projects apiece, like iLEAPS, and helped set international research agendas.

But what I hadn't bargained for was the *added* value of these programs through their input into international policy and their national committees. IGBP has 74 national committees and a database of over 10,000 researchers across all continents barring Antarctica. Alongside IGBP's core projects, the national committees are what give IGBP its far-reaching influence.

What do I mean by influence? The 2009 review of IGBP by the International Council for Science (ICSU) states: "The success and



recognition of the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Ecosystem Assessment (MA) both owe a huge amount to the work of IGBP.” ICSU’s new vision and strategic framework for Earth-system research also reports that its four global-change programs, which include IGBP, have a disproportionate influence on the worldwide investment on global environmental-change research, estimated to be nearly two billion euros per year.

In the IPCC Fourth Assessment Report for example, IGBP suggested authors, fed into the outline of the report, nominated experts, took part in the reviews, and drove a workshop to identify gaps and uncertainties in the report. This workshop articulated what research is needed to fill knowledge gaps and reduce uncertainties. In November 2009, we held a joint IGBP-IPCC meeting in Brazil on influence, adaptation and vulnerabilities in the least developed nations.

The national committees help IGBP focus its science agenda and ensure our work is addressing the key challenges facing societies everywhere. They are a way of helping IGBP align its research priorities with funding agency priorities at a national level. This is essential because all our funding comes from these agencies. The national committees provide a mechanism for national global-change research communities to have a voice at the international level and they help disseminate key findings from the international community to national stakeholders.

One of my first tasks when I joined IGBP was helping write and edit a summary for policymakers on ocean acidification. IGBP, the Scientific Committee on Oceanic Research (SCOR) and other sponsors of our ocean acidification symposium series helped distribute the summary to international stakeholders, the United Nations Environ-

ment Program (UNEP), United Nations Educational, Scientific, and Cultural Organisation (UNESCO) and many others. But the national committees provided a valuable mechanism for distributing findings from our symposia to national stakeholders, environment agencies and ministries, funding bodies, and national non-governmental organisations. IGBP’s projects could make more use of this valuable resource.

So valuable are these networks to IGBP that we have developed a new communications strategy specifically for the national committees to improve their effectiveness. Currently, of our 74 national committees around 40 are active, making substantial contributions to the program. Others have a smaller influence, and this needs to be addressed. We have a number of aims with the strategy:

- ❑ to engage a broader scientific community and initiate regional activities and networks driven by national committees. This will create a stronger global-change community
- ❑ to align internationally coordinated research with national research agendas
- ❑ to develop closer ties between policy- and decision-makers and the researchers who can inform policy-makers and influence implementation
- ❑ to make it easier for people from very different disciplines and regions to work together to address complex issues
- ❑ to use the vast amount of existing environmental research and data more effectively. I will be sending round the draft strategy for comments before the end of 2009.

While this may sound like a top-down strategic approach, IGBP also works equally effectively as a grassroots, bottom-up organi-

sation with scientists from projects and national committees identifying research priorities and driving the agenda. The projects do this through annual meetings of the projects and by attending IGBP scientific committee meetings. The 74 national committees influence IGBP for example through regular congresses, held about every four years. The last was in Cape Town in 2008. Around 380 people participated and the event led to two important new initiatives: regional alliances of global-change national committees in Africa and Europe.

Each year, national committees host IGBP governance meetings—officers meetings, scientific meetings, meetings of international project offices—in different countries around the world. Using this opportunity, dedicated workshops and symposia are jointly organised by national and visiting steering committees. This is a good way for international and national researchers to meet.

Increasingly, governments acknowledge the fact that countries in the same region face similar global-change challenges. It makes sense for scientists in these regions to integrate better. Regional alliances will be part of a framework for effective communication and coordination at a national, regional and international level. This mechanism can ensure research results are put to the best use by policymakers on the temporal and spatial timescales of relevance to them: regionally and from days to decades.

We encourage scientists actively engaged in IGBP projects to join their own national committee and contribute to regional and international global-change research efforts. If your country does not have one, start one! ■

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National Activities



People in the photo: Prof. Dia-Eddin Arafah (Chair) – sitting in the center.

People starting from right: Prof. Jamil Khalifeh (Member), M.Sc. Rasha Abu Ruzz (Scientific Secretary), Dr. Joao Morais (IGBP Secretariat), Prof. Mohammad Isam Yamani (Member), Prof. Mofid Azam (Dean of Scientific Research, University of Jordan), Doc. Tareq Hussein (NC Ambassador).

Tareq Hussein¹ and Dia-Eddin Arafah²

1. University of Helsinki, Department of Physics, Helsinki, Finland

2. University of Jordan, Department of Physics, Amman, Jordan

An IGBP National Committee in Jordan: another step towards environmental solutions

The Hashemite Kingdom of Jordan is situated at the junction of the Levantine and Arabian areas of the Middle East. The total area of Jordan is approximately ninety thousand square kilometers. Even though the country is small, it features a variety of diverse terrain and landscapes. In the western part, which comprises about 25% of the country, the climate is Mediterranean. The rest of the country has a desert climate.

The population of Jordan is about 6 million. The majority of the people are Arabs, and the minorities include Circassians, Chechens, and Armenians. More than 90% are Sunni Muslims followed by Christian,

Shi'a, and Druze. Jordan values its diverse population and provides for their cultural rights. The constitution also protects women and children.

Jordan's natural resources are modest. Therefore, the country has focussed on developing its human potential through educational and health standards that aim to strengthen the economy through skilled labour. Even though the country has faced daunting political and socio-economic challenges, it has succeeded in maintaining and developing its greatest asset, its education system, since the formation of the country in the early 1920s. To date,

there are over 3453 government-sponsored schools, 2231 private schools, 51 community colleges, and 28 universities.

Environmental challenges and national efforts to reverse the environmental decline

The land of Jordan is famous for its lush vegetation and wildlife as described by many recent historians and travellers ("land of milk and honey"). However, Jordan's natural environment has declined significantly during the 20th century. The main reasons are desertification, rapidly expanding

population, industrial pollution, wildlife hunting, and habitat loss because of development.

The biggest environmental challenge that Jordan faces today is the scarcity of water. Water resources per capita are among the lowest in the world. The situation is even more difficult because Jordan shares most of its surface water resources with neighbouring countries, the water resources have fluctuated around a stationary average, and the country's population has continued to increase.

In recent decades, Jordan has taken steps to reverse the environmental decline. Several non-governmental and governmental organisations, including the Ministry of Education, are actively involved in educating the population about environmental issues and introducing new literature to government schools to promote awareness of environmental issues.

Jordan was also the first country in the Middle East to adopt a National Environmental Strategy. The Strategy includes specific recommendations for Jordan on a sectoral basis addressing the areas of agriculture, air pollution, coastal and marine life, antiquities and cultural resources, mineral resources, wildlife and habitat preservation, population and settlement patterns, and water resources. The Strategy document was completed in 1992 by a team of over 180 Jordanian specialists with the help of the International Union for the Conservation of Nature (IUCN).

Recent interest in air pollution studies

The number of air pollution scientists has increased in Jordan during the last decade and the interest in this field has attracted more graduate students. Currently, three public universities (University of Jordan in Amman, Yarmuk University in Irbid, and Hashemite University in Zarqa) in addition to several public organisations and institutions support air pollution studies and host national expertise either by offering permanent positions or through short-term projects.

Despite the interest, air pollution research is still limited in Jordan because of the absence of routine monitoring of



ambient air pollution and lack of data on air quality. However, efforts towards making new studies and air quality evaluation and assessment are increasing in different parts of the country.

IGBP-NC in Jordan

Although Jordanian expertise in the field of air pollution has increased, combining the efforts of the scientists is important. In November 2008, we started an initiative to establish a National Committee (NC) for the International Geosphere-Biosphere Programme (IGBP).

After several months of planning, the Committee was established in May 2009 directly after a visit by Dr. Joao de Morais, Deputy Director of IGBP, at the University of Jordan. In his presentation, Dr. Morais outlined current environmental problems in the world and the role of IGBP in addressing them. During the same visit Dr. Tareq

Hussein, Docent at the University of Helsinki, also presented research results on environmental and health threats of urban air pollution on local and regional scales.

The members of the National Committee now include five scientists from the University of Jordan and the Hashemite University. Dr Hussein from the University of Helsinki is a sixth member acting as the IGBP ambassador.

Although the National Committee is still at an early stage, new members are expected in the near future from other institutions and stations such as Yarmuk University, the Marine Science Station in Aqaba, and the Environmental Studies and Monitoring Section from the Aqaba Special Economic Zone Authority.

As a further step towards international collaboration, a short-term measurement campaign between the University of Jordan and the University of Helsinki was conducted in parallel with the establishment of the IGBP-NC. This campaign took place in Amman during April and May 2009 and its aim was to assess the number concentration level of aerosol particles in Amman.

In the near future, the National Committee aims to build a stationary and mobile measurement station at the University of Jordan in close collaboration with the Division of Atmospheric Sciences and Geophysics at the University of Helsinki. This will hopefully boost air pollution studies in Jordan in the long term and help to initiate further collaboration with the international community. ■

Members of the IGBP National Committee of Jordan:

University of Jordan

Prof. Dia-Eddin Arafah, chair
Prof. Jamil Khalifeh
Prof. Mohammad Isam Yamani
M.Sc. Rasha Abu Ruzz

Hashemite University

Dr. Mahmoud Abu-Allaban

University of Helsinki

Dr. Tareq Hussein

Novel data mining strategies for exploring biogeochemical cycles and biosphere-atmosphere interactions

Markus Reichstein, Miguel Mahecha and Nuno Carvalhais

Max Planck Institute for Biogeochemistry, Jena, Germany

In June 2009, around 30 scientists from a diversity of research fields, such as climatology, biogeochemistry, ecosystem and organismic ecology, information science, mathematics, and machine learning met for an international workshop at the Max Planck Institute for Biogeochemistry in Jena.

The overall goal of this workshop was to explore suitable methodologies for analysing observations of biosphere-atmosphere interactions and to identify the conceptual challenges posed by different data streams.

Biogeochemists and ecologists discussed with researchers actively involved in the development of multidimensional time series analysis, data assimilation and machine learning. In particular, data mining (or machine learning)—the art of designing algorithms capable to automatically recognize complex patterns in different data streams—has so far almost exclusively been developed in the context of genetics, and speech, face or text recognition.

From the perspective of the environmental and atmospheric sciences, a major interest was to explore how novel machine-learning methods can help with the interpretation of biosphere-atmosphere interactions.

In particular, pattern recognition within the continuously growing multidimensional data arrays, such as simultaneous observations of ecosystem-atmosphere trace gas and energy fluxes together with meteorological and remote sensing observations, has attracted much attention. For example, the inference of causal relationships, lag and memory effects from time series data was raised in the discussion as an important

problem. We further discussed how to quantify relationships among different observations that are often non-linear and change across time-scales (frequencies) and in time.

This workshop highlighted that the Earth System in general, and biosphere-atmosphere observations in particular, pose challenges to machine-learning research at least as interesting as in fields where such methods are currently applied. We identified a number of particularly interesting data sources which call for sophisticated analysis using machine-learning methods:

- ❑ Fluxes of trace gas and energy exchange data (observed by the eddy covariance method) along with a variety of ancillary variables constitute multi-variate time series. They allow investigations of ecosystem-atmosphere interactions from half-hourly time steps to decadal variations at multiple sites.
- ❑ Atmospheric carbon dioxide (CO₂) concentration data with even longer time series (of several decades) which integrate very large geographical regions.
- ❑ Remote sensing data with continuous temporal and spatial coverage over decades ('3D-data cubes', Fig. 1).
- ❑ Webcam streams of ecosystems requiring challenging image analysis.
- ❑ Spatially distributed data of species abundances which, because of its many dimensions and the complexity of the underlying processes, would benefit from a data mining approach.

Typical machine-learning approaches deemed promising for the various observations and questions include non-linear dimensionality reduction and classification (Fig. 1), advanced time-series analysis, inference of causality and information flow, and, last but not least, statistical learning for statistical prediction, such as regression trees and neural network approaches.

A particular challenge is to simultaneously extract joint patterns from data streams which are very different in terms of resolution, extent and signal-to-noise ratio. Such data streams are typical for the diverse Earth Observation data. A discussion paper on these issues also in relation to future evaluations of terrestrial biosphere and climate models is planned.

Further information can be found at www.bgc-jena.mpg.de/bgc-mdi/bgc-data_mining

A mailing list for discussions and circulation of interesting news on the topic has been established as bgc-data_mining@bgc-jena.mpg.de

New subscriptions are welcome. We would like to thank the Max Planck Society and the Max Planck Institute for Biological Cybernetics, Department for Empirical Inference, for co-funding and cooperation. ■

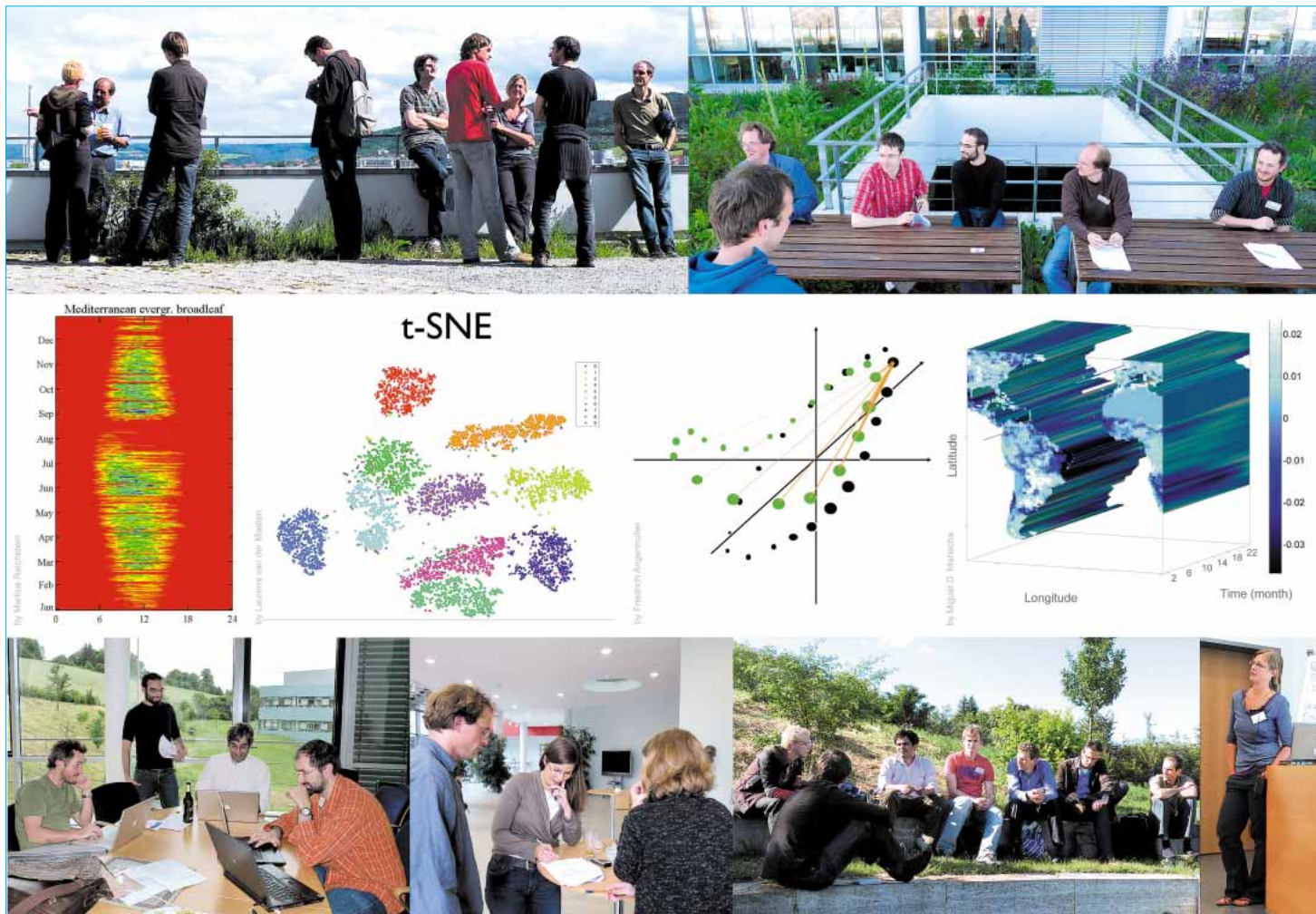


Figure 1. Impressions from the workshop: lively discussions took place in plenary sessions as well as break-out groups and social events. In the middle row a selection of the discussed issues is shown: (left) an eddy-covariance fingerprint of carbon fluxes at Puéchabon a Mediterranean flux site (M. Reichstein; data: S. Rambal); (middle) the result of a low-dimensional representation of a handwritten digit data set (L. van der Maaten); (right) a methodological illustration of a recurrence analysis (F. Angermüller), the 3D data cube (M. Mahecha).

List of participants:

Gab Abramowitz
Hella Ahrends
Natasa Atanasova
Susana Barbosa
Pierre Brender
Nuno Carvalhais
Philippe Ciais
Michel Crucifix
Edouard Davin
Reik Donner
Tim Häring
Stefan Harmeling
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Torsten Hothorn
Dominik Janzing
Martin Jung
Praveen Kumar
Jürgen Kurths

Gitta Lasslop
Sebastian Luyssaert
Miguel Mahecha
Nishant Malik
Antje Moffat
Boris Orłowsky
Grigory V. Osipov
Dario Papale
Raphael Proulx
Markus Reichstein
Andrew Richardson
Henning Rust
Bernhard Schölkopf
Boris Schröder
Carolin Strobel
Mika Sulkava
Laurens van der Maaten

Aerosols, Clouds, Precipitation, Climate (ACPC) program

Science Plan & Implementation Strategy

Anni Reissell

iLEAPS International Project Office

Interactions among the aerosol, clouds, and precipitation are key components of the climate system. The goal of the Aerosols, Clouds, Precipitation, Climate (ACPC) research program is to *obtain a quantitative understanding of the interactions among aerosol particles, clouds and precipitation, and their role in the climate system*. Here, the motivation and outline of the ACPC Science Plan and Implementation Strategy is briefly presented.

ACPC is a joint initiative of the International Geosphere–Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP). The ACPC program

has been developed through cooperation between iLEAPS (the Integrated Land Ecosystem–Atmosphere Processes Study) and IGAC (International Global Atmospheric Chemistry), two core projects of IGBP, and GEWEX (Global Energy and Water Cycle Experiment), a core project of the WCRP.

The atmospheric aerosol, in part through its interactions with clouds, is one of the most important sources of uncertainty in estimates of climate forcing of the Anthropocene (period since about late 18th century with significant global anthropogenic influence on the Earth's climate and ecosystems).

Moreover, clouds are the largest source of uncertainty in estimates of equilibrium climate sensitivity (equilibrium change in global mean near-surface air temperature that would result from a sustained doubling of the atmospheric (equivalent) CO₂ concentration); and precipitation is perhaps the most poorly quantified yet essential climate variable.

The aerosol, clouds and precipitation are a strongly coupled system but the nature of this coupling and its sensitivity to perturbations in one of the elements is poorly understood.

Recent developments in process understanding, modelling, and observational capabilities now enable us to address the long-standing and fundamental questions related to the nature of the interplay between the aerosol, clouds and precipitation.

ACPC has been established to facilitate and enable international and interdisciplinary research directed toward answering the following questions:

- How do the amount and properties of the atmospheric aerosol affect cloud microstructure and precipitation-forming processes?
- In what way do aerosol particles influence the efficiency of precipitation (ratio of total precipitation to total available moisture)?
- How do elevated heating anomalies resulting from light scattering and absorption by aerosol particles affect the distribution of clouds and precipitation?
- How do aerosol-driven changes in the vertical structure of latent heating affect the subsequent development of circulation systems? The scales range from the cloud or cloud system to the regional and global. To what extent do changes in clouds, precipitation, and circulation systems regulate the distribution of the aerosol itself?

The nature of the coupling of the aerosol-cloud-precipitation system depends very much on the prevailing cloud regime. Therefore, ACPC has developed its research strategy around the study of specific cloud regimes.

The chosen regimes represent climatologically important cloud formation and precipitation environments with strong indications of aerosol-cloud-precipitation interactions; they include some of the major convective and precipitating environments: the monsoon systems, organised deep convective systems over land, tropical cyclones, and marine shallow and deep cumulus convection. Other regimes have been selected because they are suitable for studying key processes. These include orographic clouds, diurnally variable convection over land, and mixed-phase clouds, including those that produce lightning and hail.

Large-scale models include aerosol-cloud-precipitation processes in a very crude and highly parameterised fashion. A key issue for the ACPC research program is to investigate how improved process-level understanding of aerosol-cloud-precipitation interactions can be efficiently incorporated into large-scale models to constrain or improve estimates of the global effects of aerosol, clouds, and precipitation on climate. The regime-based approach will help also in this context.

The ACPC program aims to:

1. act as a forum for bringing together the diverse expertise necessary to advance our understanding and help coordinate international efforts;
2. ensure that experimental strategies encompass a sufficiently wide range of aerosol variability to properly characterise aerosol-cloud-precipitation interactions for the relevant regimes;
3. coordinate and synthesise the findings of various components of the program;
4. provide continuity and perspective for research initiatives.

The Science Plan and Implementation Strategy of the Aerosols, Clouds, Precipitation, Climate research program describes the impetus for large observational, modelling, and theoretical efforts to understand the interplay amongst clouds, aerosol and precipitation.

The document gives examples of proposed measurement strategies for focused field studies: local and statistical closure studies. These examples help stimulate further inputs from the broader scientific community to meet the objectives of ACPC.

The implementation plan also includes the research guidelines, organizational background, project management, activities, capacity building and knowledge transfer. Finally, the document lists some relevant background reading.

The document was prepared mainly by the present and past members of the ACPC Steering Committee and submitted to external review process. The ACPC Science Plan and Implementation Strategy will be available as an electronic version and also as printed document in the beginning of 2010.

The ACPC Steering Committee welcomes further inputs from the broader scientific community to meet the objectives of ACPC! ■

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As an international scientific program, the implementation of ACPC includes a strategy that uses coordinated and ongoing field studies to integrate six strategic elements. The elements identified are as follows:

- *a focus on regimes where there are strong indications of aerosol-cloud-precipitation interactions*
- *an emphasis on statistical characterisation of aerosol-cloud-precipitation interactions*
- *the development of approaches that leverage past and ongoing activities*
- *thorough integration of modelling and observational activities*
- *a hierarchical approach to both modelling and data collection/analysis*
- *continued development of measurement techniques.*

ACPC web page:
www.ileaps.org/acpc

ACPC mailing list:
acpc@ileaps.org

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PYRN envisions spreading permafrost science and information among young researchers looking at permafrost environments around the globe. PYRN aims at gathering and redistributing information, furthering international cooperation and promoting the ideas and results emanating from permafrost research.



IPA - International Permafrost Association

PYRN will be formally established under the patronage of IPA and will create and maintain means of communication among young researchers involved in permafrost research.



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PYRN-Bib

A Bibliography of Permafrost-Related Theses Sponsored by the Permafrost Young Researchers Network

PYRN-Bib synthesizes all student theses with a permafrost-related topic in an international bibliographical database.

PYRN-Bib is a fully educational project hosted by the Permafrost Young Researchers Network <http://pyrn.ways.org>, an international network of early career students and young scientists in permafrost related research fields with currently more than 720 members with backgrounds ranging from geology to ecology to astrobiology to engineering to biogeochemistry to numerical modelling.

PYRN-Bib is published online under the patronage of the International Permafrost Association (IPA)

Goals of PYRN-Bib

- Generating a comprehensive bibliographic database on permafrost theses for the science community
- Providing unique, previously hard to find information including theses published in languages other than English
- Widely disseminating permafrost-relevant bibliographic information
- Soliciting PYRN membership
- Providing a mean to map the evolution of the nature of permafrost-related research over the last decades, including regional trends, shifts in research direction, and/or the place of permafrost research in society.

- PYRN-Bib now hosts more than 900 entries from 22 countries covering the period 1951–2009
- PYRN-Bib is online: <http://pyrn.ways.org/resources/pyrn-bib-permafrost-bibliography>
- PYRN-Bib can be downloaded in various formats: tagged Endnote library, XML, BibTex, PDF
- PYRN-Bib anytime accepts new relevant theses and old theses not yet catalogued

Grosse, G. & Lantuit, H. 2008. PYRN-Bib 3.2: The Permafrost Young Researchers Network Bibliography of Permafrost-Related Theses. Permafrost Young Researchers Network, 72 pp.
(Permanent handle: <http://hdl.handle.net/10013/epic.31101>)

PYRN-Bib



Figure 1. Modelled permafrost temperatures in Northern Eurasia (mean annual temperature at the permafrost surface) averaged over (a) 1980–2000 and (b) 2080–2100 time intervals [1, 2].

NEESPI - the Northern Eurasia Earth Science Partnership

The fate of European permafrost

Northern Eurasia, the largest landmass in the northern extratropics, accounts for ~20% of the global land area. Yet little is known about how the biogeochemical cycles specific to this carbon-rich, cold region interact with global climate. A major concern is that changes in the distribution of land-based life, as well as its interactions with the environment, may lead to a self-reinforcing cycle of accelerated regional and global warming.

With this motivation, the Northern Eurasian Earth Science Partnership Initiative (NEESPI) was formed in 2004 to better understand and quantify feedbacks between Northern Eurasian and global climates. The first group of NEESPI projects has mostly focussed on assembling regional data bases, on organising improved environmental monitoring of the region, and on studying of individual environmental processes.

More recently, the NEESPI research focus has been moving towards integrative studies, including the development of modelling capabilities to project the future state of climate, environment, and societies in the NEESPI domain. This effort will require a high level of integration of observation programs, process studies, and modelling across scientific disciplines.

Permanently frozen soils are susceptible to widespread thaw and degradation due to rising surface temperatures. Permafrost thaw,

which is already occurring at the southern limits of the permafrost zone, can dramatically alter ecosystems and has adverse impacts on infrastructure [1, 2].

Thawing also releases greenhouse gases, in quantities potentially significant to the global carbon cycle, from recently frozen and inactive organic carbon pools in the permafrost zone. Deepening of the active layer (top layer that thaws in summer) above the permafrost, resulting from warming air temperatures, could dramatically alter the hydrological cycle and lake and wetland dynamics.

As part of NEESPI, permafrost scientists from fourteen institutions in Eurasia and Alaska have joined their efforts to merge permafrost temperature observations in Russia, Kazakhstan, the United States, and Mongolia [2]. They have established a modern permafrost monitoring network, with more than 100 boreholes in Eurasia already equipped with standard temperature sensors and loggers. In 2006, the data from many of these sites became readily available.

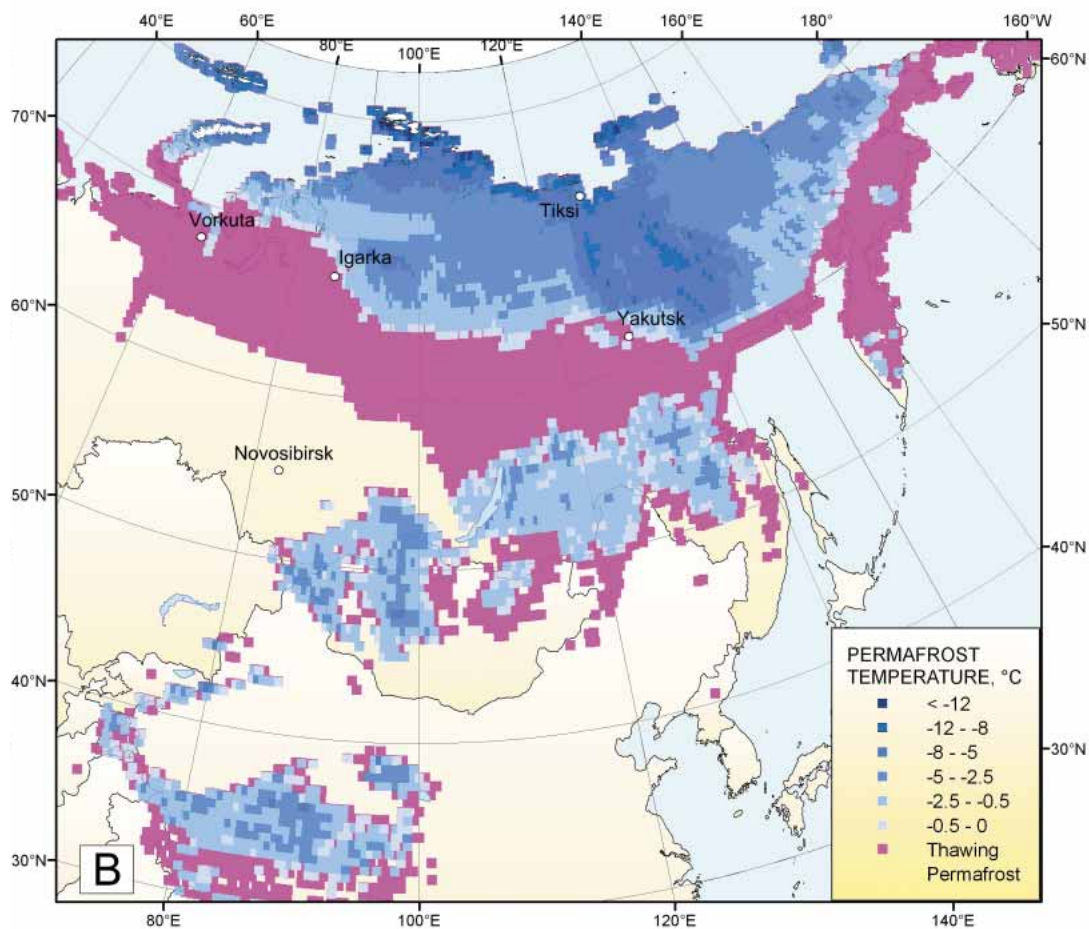
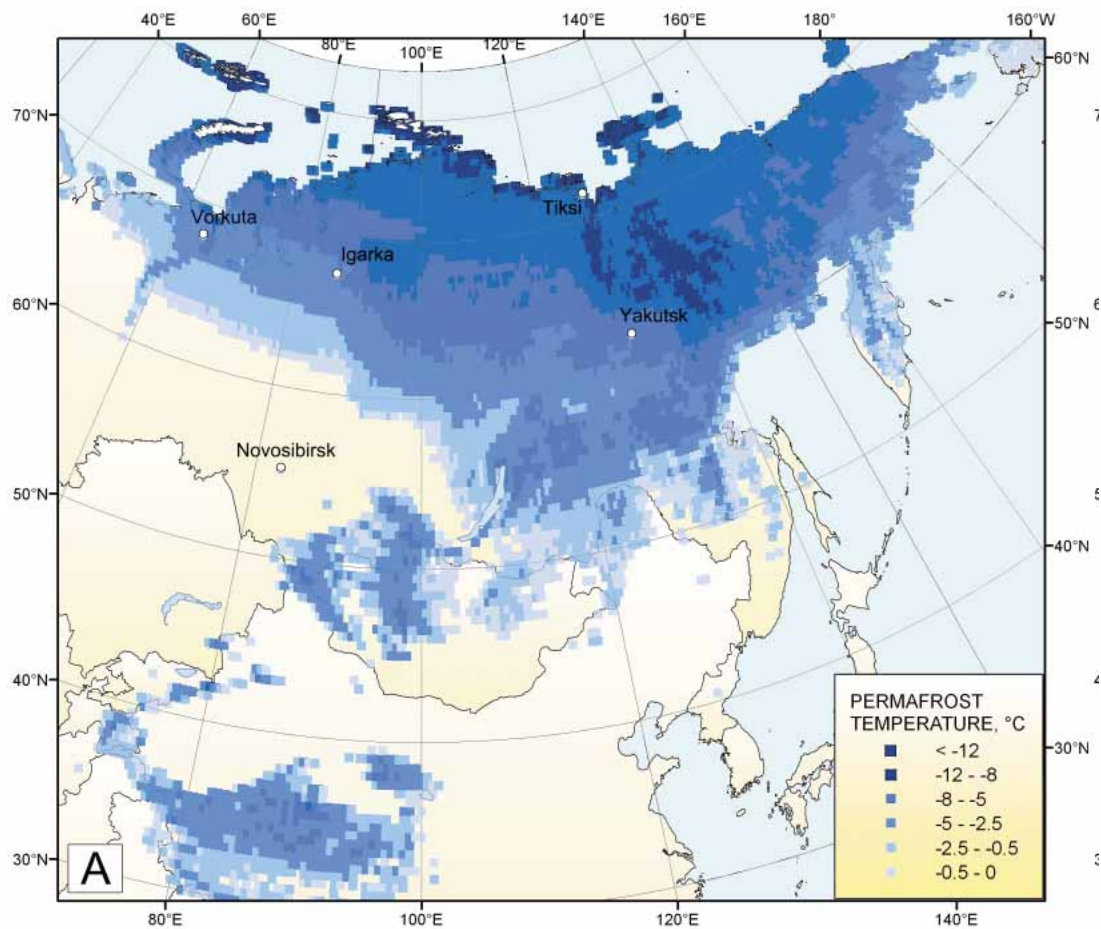
Some preliminary work has been conducted to predict the response of regional permafrost changes to future climate warming (Fig. 1). According to this model, by the end of the 21st century, currently discontinuous permafrost (temperatures between 0 and –2.5°C) will have warmed to the point of active thaw. Permafrost degradation will

probably be most significant in west and south Siberia [1, 2]. These simulations suggest that almost all permafrost in Europe will be thawing by the end of the 21st century. ■

Text adapted from [3].

<http://neespi.org>

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EUCAARI - European Integrated Project on Aerosol-Cloud-Climate and Air Quality Interactions

Heat waves lead to elevated ozone concentrations through multiple feedbacks

Summer 2003 was exceptionally warm in Europe. At the same time, ozone (O_3) concentration increased to highest levels since the late 1980's. Atmospheric trace species measurements in the boundary layer suggested a number of positive feedbacks between the weather conditions and atmospheric composition that played a role in the process [1].

Isoprene, one of the most abundant biogenic volatile organic compounds in the atmosphere, is mainly emitted by deciduous trees in the world's forests and an important precursor of O_3 . In 2003, isoprene concentrations were high compared to previous years, and regional-scale model calculations indicated that such enhanced levels of biogenic isoprene could have contributed up to 20% of the peak ozone concentrations. Another reason was that the anticyclonic conditions during the ozone episodes were accompanied by an extended residence time of air parcels in the atmospheric boundary layer, a low total ozone column (total number of ozone molecules in the vertical) and a reduced cloud cover, all favouring ozone formation.

Furthermore, during drought, dry deposition on leaf surfaces decreases because the plants keep their stomata closed. Sensitivity runs with a global chemical transport model showed that such a reduction in the surface dry deposition could also have contributed significantly to the enhanced ozone concentrations. Finally, high temperatures and drought initiated extensive forest fires in the

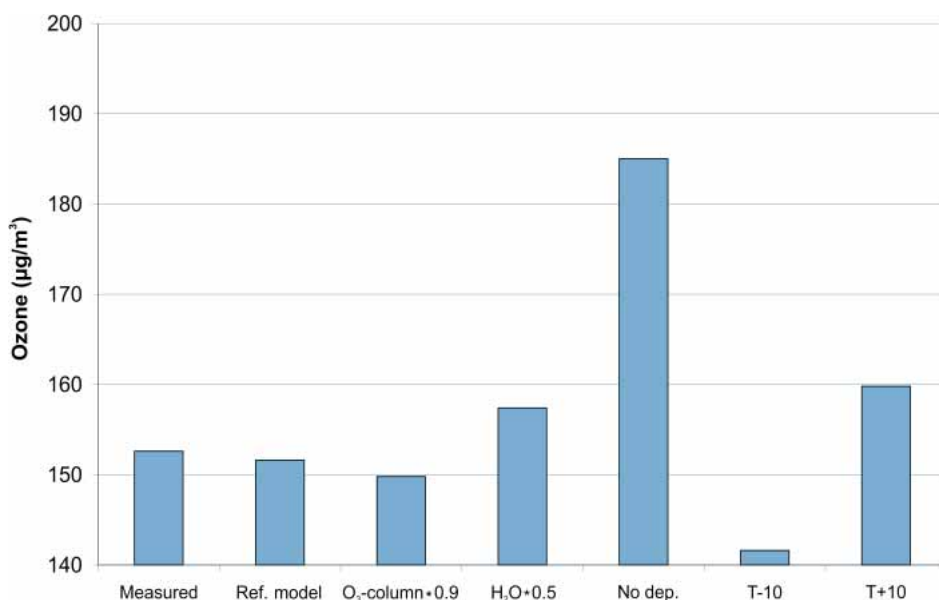


Figure 1. Modelled response of ozone to various perturbations. The bars show the maximum ozone concentration at the peak of the heat wave, on 8 August 2003, averaged over eight monitoring sites. The left bar gives the measured value. The following bars show results from various model scenarios: the reference model; total ozone column reduced by 10%; water vapour concentration reduced by 50%; surface deposition of ozone set to zero; air temperature decreased by 10 °C and increased by 10 °C.

Iberian peninsula that, in turn, contributed to the peak ozone values observed in North Europe in August.

Because of climate change, such heat waves may occur more frequently in the future and may gradually overshadow the effect of reduced emissions from anthropogenic sources of volatile organic compounds (VOC) and nitric and nitrogen oxides

(together referred to as NO_x) in controlling surface ozone. ■

www.atm.helsinki.fi/eucaari

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PCMIP - PalaeoCarbon Modelling Intercomparison Project

A new project for quantifying the climate – carbon cycle feedback

Climate-induced changes in the terrestrial biosphere and the ocean modulate the release and uptake of carbon dioxide and this, in turn, alters atmospheric composition and climate through the climate – carbon cycle feedback. The Coupled Climate - Carbon Cycle Model Intercomparison Project (C⁴MIP) has used models of the terrestrial and oceanic carbon cycles in ocean-atmosphere general circulation models to show that although the feedback is positive, its magnitude is highly uncertain.

One approach to reducing this uncertainty is to evaluate carbon-cycle models against observations of the contemporary carbon cycle. Attempts to use modern observations to constrain climate sensitivity have had limited success so additional constraints are being sought from records of past climate change. Similarly, past variations in climate and CO₂ concentration could be used to provide constraints on the climate-carbon feedback. At its kick-off meeting at Dartington Hall, UK, in January 2009, the PalaeoCarbon Modelling Intercomparison Project (PCMIP) defined a strategy to quantify the carbon-climate feedback based on simulations of the past millennium and of the Last Glacial Maximum (approximately 21000 yrs BP).

The simulations of the last millennium will be made in collaboration with the Palaeoclimate Modelling Intercomparison Project (PMIP). PMIP is running simulations of the last millennium (850–1850 AD), using prescribed greenhouse gas forcing. PMIP

models with an interactive carbon cycle will simulate the implied partitioning of CO₂ between land, ocean, and atmosphere. PCMIP will run the same simulation allowing the models to calculate atmospheric CO₂, thus providing a stringent test of the ability of current Earth System Models (ESM) to simulate the co-evolution of climate and CO₂.

PCMIP will also run diagnostic-mode carbon-cycle simulations of the Last Glacial Maximum to show whether ESMs can reproduce the observed glacial-interglacial change in terrestrial, oceanic, and atmospheric carbon storage. Offline ocean - carbon cycle model experiments will be used to evaluate the importance of, for example, temperature-controlled changes in solubility, ocean circulation effects, and iron fertilisation by dust in explaining the observed CO₂ drawdown.

PCMIP is coordinated by A. Abe-Ouchi, P. Friedlingstein, S.P. Harrison, and I.C. Prentice and is sponsored by the IGBP (International Geosphere-Biosphere Programme) project AIMES (Analysis, Integration, and Modelling of the Earth System) and the UK NERC (Natural Environment Research Council) QUEST (Quantifying and Understanding the Earth System) program. ■

PCMIP is sponsored by IGBP core project AIMES and UK MERC QUEST program.

www.bridge.bris.ac.uk/projects/pcmip

New SSC Co-Chair

Markku Kulmala

markku.kulmala@helsinki.fi

Markku Kulmala, Professor and Head of the Division of Atmospheric Sciences of the Department of Physics at the University of Helsinki, Finland, has been nominated as co-chair of iLEAPS for the next three years. He will be co-leading the iLEAPS Scientific Steering Committee (SSC) during 2010–2012.

Prof. Kulmala is one of the leading aerosol scientists in the world with broad experience and interest in biosphere-atmosphere research. He has published over 500 articles on atmospheric aerosols, clouds and biosphere-atmosphere interactions.

He has received several science awards: the latest was the European Geophysical Union Bjerknes medal in 2007 for his outstanding contributions to aerosol science and to the creation of a new discipline, *terrestrial ecosystem meteorology*, an interdisciplinary field of research within meteorology and biology addressing atmosphere-ecosystem interactions.

During the academic year 2009–2010, Prof. Kulmala is working as the King Carl XVI Gustaf Visiting Professor in Environmental Science in Stockholm, Sweden.



Prof. Kulmala's scientific work covers theoretical and experimental physics, theoretical and observational meteorology, and biophysics. He has published more than 300 papers in peer-reviewed journals and been actively involved in supervision, educational, and organisational activities. His world-renowned research addresses the following key topics:

1. Formation and growth mechanisms of atmospheric aerosols and aerosol dynamics;
2. The effect of secondary biogenic aerosols on global aerosol load;
3. Aerosol-cloud-climate interaction;
4. The relationships between the atmosphere and different ecosystems, particularly boreal forest.

His approach starts from basic nucleation theories followed by models of aerosol dynamics/atmospheric chemistry and laboratory experiments and ends in broad-ranging long-term field measurements (in particular at the University of Helsinki research stations) and 3D modelling.

His interdisciplinary research is complemented by an interdisciplinary team and the use of a wide range of modern scientific technologies, including analysis of satellite data together with point measurements and

3D-models. A combination of personal fundamental research and leadership in large collective projects, for example the co-ordination of large EU projects, has allowed Markku Kulmala to considerably advance our knowledge of biosphere-atmosphere and biosphere-aerosol-cloud-climate interactions.

As Co-chair of iLEAPS, Prof. Kulmala plans to advance the expansion of existing field stations to comprehensive continuous measuring sites. He is already investigating possibilities of founding new ones in China, Estonia, and Sweden.

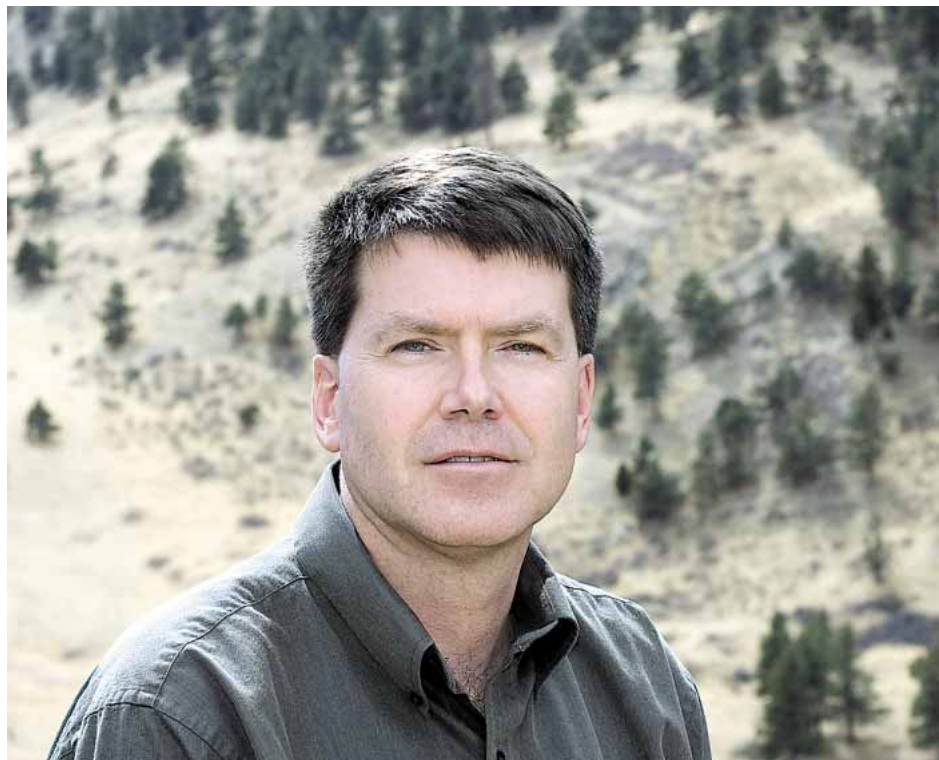
According to Prof. Kulmala, the path to comprehensive measuring stations includes several steps ranging from simple, mobile stations typically built in easily transportable caravans to full-scale stations, such as SMEAR II in Hyytiälä, southern Finland, where the atmospheric and ecosystem components of the measuring system are linked seamlessly (www.atm.helsinki.fi/SMEAR).

At such a station, combining observations and modelling becomes possible and the same data lends itself to the study of different scales: from molecule to global circulation and from cell to forest. ■

New SSC member

Gordon Bonan

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Dr. Bonan is Senior Scientist and Head of the Terrestrial Sciences Section in the Climate and Global Dynamics Division at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, USA. He is an expert in the development of and experimentation with coupled ecosystem-climate models to study the interactions of terrestrial ecosystems with climate. His research integrates ecological, hydrological, and atmospheric sciences to examine natural and human changes in land cover and ecosystem functions and their effects on climate, water resources, and biogeochemistry.

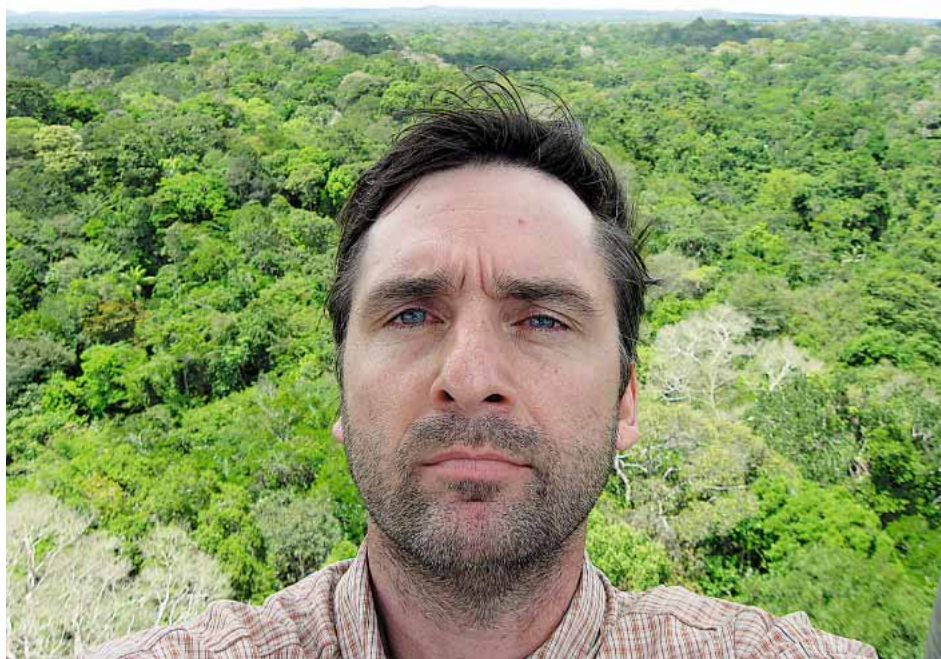
Dr. Bonan has served on the editorial boards of various atmospheric and ecological journals, including *Journal of Climate* (1998–2003). He has also been a member of various national boards in USA including the Climate Research Committee (2001–2003) and the Community Climate System Model (CCSM) Scientific Steering Committee (2003–2009). He has led the CCSM land model working group and its development of the Community Land Model (1997–2006) and currently leads the CCSM biogeochemistry working group.

He received a PhD in environmental sciences from the University of Virginia in 1988 and has been at NCAR since 1989. He has published over 100 articles in various scientific journals and reports. ■

New SSC member

Alex Guenther

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Dr. Guenther is a Senior Scientist and Section Head of the Atmospheric Chemistry Division of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, USA.

He is an expert on biogenic volatile organic compound (VOC) emissions and their role in the Earth system. He has led a research group on more than 40 field investigations of biosphere-atmosphere interactions on six continents, many of them as a component of international research programs. He received his PhD in Civil and Environmental Engineering at the Washington State University in Pullman, Washington, in 1989.

Dr. Guenther is the lead developer of the global Model of Emissions of Gases and Aerosols from Nature (MEGAN) which is widely used by the scientific community.

Dr. Guenther has published 185 peer-reviewed journal articles. Because of his ground-breaking work with VOC emission studies, his papers are also widely cited: he has an h-index of 41. Moreover, he has one paper among the "Top 10 most highly cited in geosciences" and a recent "Fast moving front" paper.

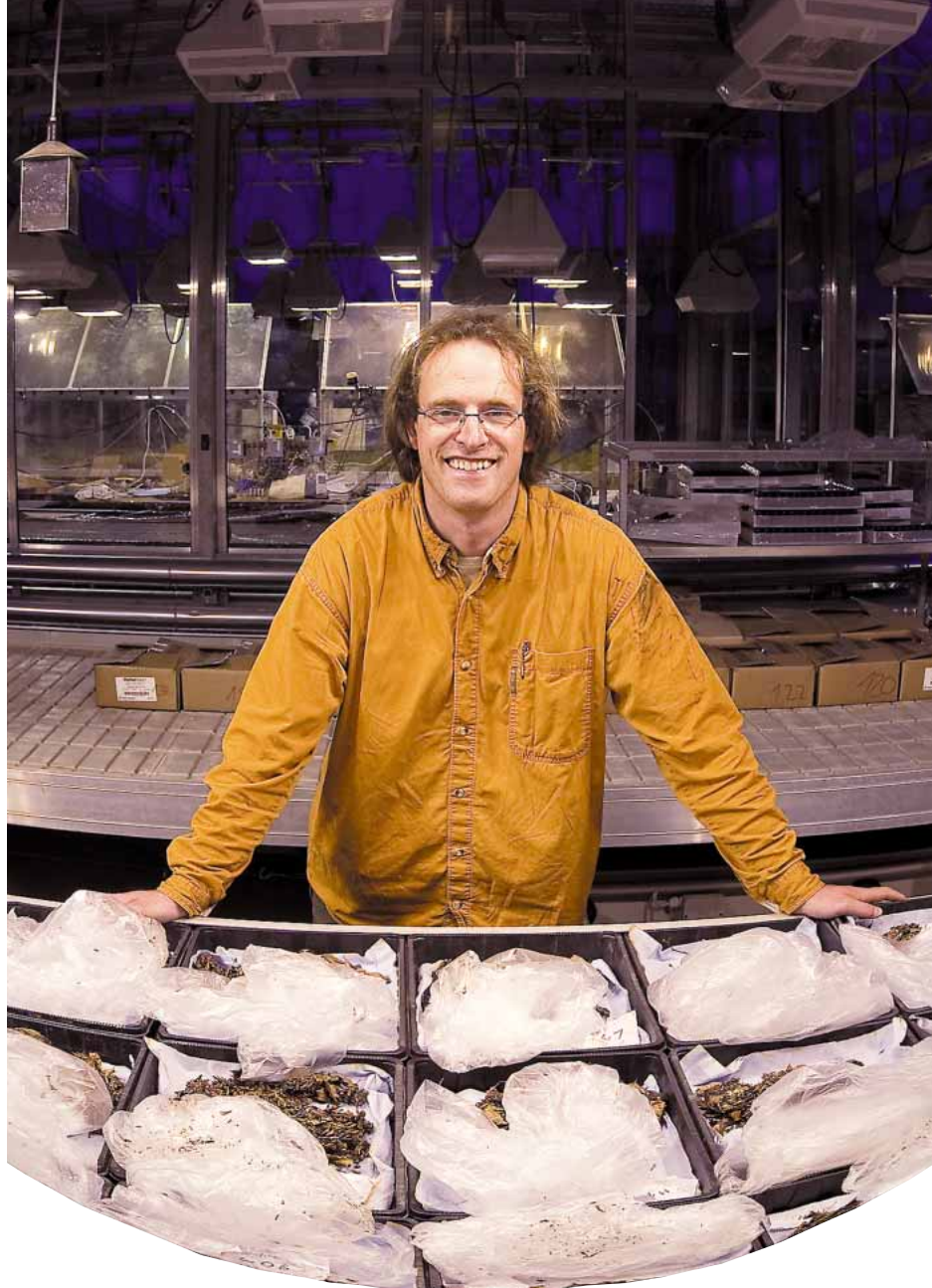
Dr. Guenther is co-chair of the International Geosphere Biosphere Programme (IGBP) Global Exchange and Interactions Activity (GEIA). He has been a contributing

author in the Intergovernmental Panel on Climate Change (IPCC) assessment and a Principal Investigator (PI) of several projects with NASA (National Aeronautics and Space Administration), EPA (US Environmental Protection Agency), and NSF (US National Science Foundation). ■

New SSC member

Markus Reichstein

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Dr. Reichstein is Head of the Biogeochemical Model-Data Integration Group at the Max Planck Institute for Biogeochemistry in Jena, Germany. His main research interests include ecosystem physiology, carbon and water cycles and their interactions from ecosystem to globe, the influence of climate variability on ecosystem functioning, and the role of soil in the Earth System. His research group combines experimental, ground- and satellite-based observations with data-driven and process-oriented models in a model-data integration approach.

Dr. Reichstein holds a Diploma in Landscape Ecology with emphasis on soils. He got his PhD in Plant Ecology from the University of Bayreuth in 2001. He then received a Marie Curie Fellowship at the University of Tuscia in Viterbo, Italy, and continued as a visiting scientist working with Steve Running

in University of Montana in Missoula, USA, and with Dennis Baldocchi in University of California in Berkeley, USA.

Dr. Reichstein has been involved in several international research projects such as CARBOEUROPE-IP and CARBOAFRICA and is currently coordinating the European Union (EU) project CARBO-Extreme as well as the European Research Council (ERC) project QUASOM (Quantifying and modelling pathways of soil organic matter as affected by abiotic factors, microbial dynamics, and transport processes) on soil carbon and water cycling. Moreover, he acts as co-coordinator in the current FLUXNET data synthesis activity which brings together world-wide eddy-covariance observations for an improved understanding of ecosystem and Earth System functioning. ■

New SSC member

Maria Assunção Faus da Silva Dias

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Dr. Silva Dias received her PhD in atmospheric sciences in Colorado State University, Fort Collins, USA, and is presently a professor at University of São Paulo (USP) in Brazil, a member of the Brazilian Academy of Sciences, and a Fellow of the American Meteorological Society.

She has been Director of the Centre for Weather Forecasting and Climate Studies (CPTEC) in Brazil, Deputy Director of the Institute of Astronomy, Geophysics and Atmospheric Sciences at USP, President of the Brazilian Meteorological Society, and vice-President of the International Association of Meteorology and Atmospheric Sciences (IAMAS).

Dr. Silva Dias has also participated in several international scientific steering committees in projects such as the Large-Scale Biosphere Atmosphere Experiment in Amazonia (LBA), the Global Energy and Water Cycle Experiment (GEWEX), the Inter-American Institute for Global Change Research (IAI), and the Biospheric Aspect of Hydrological Cycle (BAHC), a subproject of the International Geosphere-Biosphere Programme (IGBP).

Her field of work has a major focus in the tropics, Amazon basin in particular. She has lead several LBA field campaigns focussing on biosphere-atmosphere interactions in-

duced by deforestation and by biomass burning. Dr. Silva Dias has published about 100 papers and book chapters in the peer reviewed literature; she has also advised 28 master and 15 doctorate students. ■

New NEESPI Program Coordinator

Iryna Bashmakova

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Dr. Iryna Bashmakova starts as the Northern Eurasia Earth Science Partnership Initiative (NEESPI) Program Coordinator in January 2010. Overall, her task is to improve international coordination for the program and enhance linkages between various NEESPI groups. The new international NEESPI office is located at the Department of Physics, University of Helsinki, closely connected with the iLEAPS International Project Office.

Dr. Bashmakova obtained her PhD in hydrobiology at the Institute of Hydrobiology, Academy of Sciences of Ukraine in Kiev in 1985. Her research interests range from the role of bacterial associations in nutrient balance and natural self-purification processes to organic and heavy-metal contamination of the environment, in particular water ecosystems.

Since March 2008, Dr. Bashmakova has been working at the Division of Atmospheric Sciences and Geophysics, Department of Physics, University of Helsinki as manager of the European Union (EU) project TEMPUS "Development of competency-based two-level curricula in meteorology" and researcher in the scope of FP7 EU project MEGAPOLI (Megacities: Emissions, urban, regional and Global Atmospheric POLLution and climate effects, and Integrated tools for assessment and mitigation).

She has published 46 papers in Russian, German and English. She is a member of Working Groups "Microbiology and Hygiene" and "Mass and Energy Cycle" of International Association of the Danube Countries (IAD). Her biographical notes are included in the International Directory of Distinguished Leadership (7th Edition) of the American Biographical Institute and in the International Who's Who of Intellectuals (12th Edition) of the International Biographical Centre in Cambridge, UK. ■

People

Chair

National Committee for IGBP in Jordan



Dia-Eddin Arafah

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Dia-Eddin Arafah is Professor at the University of Jordan in Amman, Jordan. Previously, he has acted as Chair of the Physics Department and Dean of the Faculty of Science. He has also been appointed Dean of the Faculty of Science for the academic year 2005, Dean of Academic Research 2006 and 2007, and Vice President for Planning and Quality Assurance 2008. Currently, he is the Vice President for Scientific Faculties and Institutes at the University of Jordan.

Prof. Arafah received his PhD in physics at Sussex University in Brighton, England, in 1984. His main research interests include surface and in-depth analysis and characterisation techniques of materials and thin films. He has worked in several joint projects with USA, Germany, and Italy, and he is also involved in collaboration between the Middle East and the European Union. Currently, Prof. Arafah is working on aerosols and problems related to air pollutants in Jordan.

Prof. Arafah has played a major role in finalising, establishing, and now chairing the National Committee (NC) for the IGBP in Jordan: see articles about founding the Jordanian NC on page 38 and about IGBP national activities in general on page 36 in this issue. ■



Tareq Hussein

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Tareq Hussein is currently a Docent at the Department of Physics in the University of Helsinki in Finland. In February 2010, he will also be an Assistant Professor at the University of Jordan in Amman, Jordan. He received his MSc in physics in 1999 in the University of Jordan in the field of natural radioactivity from building materials. He then moved to the University of Helsinki and got his PhD in atmospheric sciences in 2005.

In 2006, he started working in University of Stockholm working on the problem of dust re-suspension from road surfaces and its effects on urban air quality. Finally, in 2008, he was nominated Docent in Physics at the University of Helsinki with extraordinary evaluation.

The main research interests for Dr. Hussein are indoor and outdoor aerosol particles and their dynamic behaviour. So far, he has published 41 peer-reviewed articles and been involved in several national and international research projects such as the Finnish Centre of Excellence (Physics, Chemistry, Biology, and Meteorology of Atmospheric Composition and Climate Change), EUCAARI (European Integrated Project on Aerosol Cloud Climate and Air Quality Interactions), iLEAPS (Integrated Land Ecosystem – Atmos-

Tareq Hussein (left) and Sami Haapanala at the Hyytiälä, Finland SMEAR II station (Station for Measuring forest Ecosystem – Atmosphere Relations) in December 2009.

phere Processes Study, and the IGBP (International Geosphere-Biosphere Programme). He is also the treasurer of the Finnish Association for Aerosol Research (FAAR).

Dr. Hussein has developed several useful tools for the analysis of indoor aerosol dynamics. He is actively involved in international collaboration between the Nordic countries and the Middle East, especially Jordan and Saudi Arabia. He had a major role in establishing a National Committee for the IGBP in Jordan (see page 38 in this issue) and is planning to establish a strong and efficient atmospheric research base in Jordan in the near future and increase international collaboration among the countries in the Middle East. ■

Meetings

POLARCAT Data and SPAC II Workshop,
University of New Hampshire,
Durham, New Hampshire, USA,
2–5 June 2009

The first POLARCAT data workshop brought together participants from all of the POLARCAT campaigns. The purpose of the workshop was to increase awareness of common activities where improved analysis and interpretation of results may be achieved through data sharing and cooperation.

POLARCAT, *the Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport*, is an International Polar Year (IPY) project.

The work of the POLARCAT activities is very relevant to the Short-lived Pollutants and Arctic Climate Workshops (SPAC). The joint workshop also aimed to increase understanding of processes driving rapid climate change in the Arctic and work toward understanding what immediate actions have the greatest potential benefit toward reducing anthropogenic impacts in the Arctic.

The workshop was hosted by the Institute for the Study of Earth, Oceans and Space (EOS). Organising bodies included the Norwegian Institute for Air Research (NILU) with sponsorship from the International Global Atmospheric Chemistry (IGAC) Program, the Clean Air Task Force (CATF), the Taskforce on Hemispheric Transport of Air Pollution (HTAP), and iLEAPS. More information and abstracts can be found at

<http://transport.nilu.no/projects/polarcat-1/polarcat-data-workshop>

www.polarcat.no

3rd International AMMA Conference,
Hotel Azalai Independence,
Ouagadougou, Burkina Faso,
20–24 July 2009

Researchers from around the world working on West African Monsoon (WAM) processes, predictability and climate change issues as well as on society-environment-climate interactions took part in the 3rd AMMA (iLEAPS-recognised project African Monsoon Multidisciplinary Analysis) conference to review ongoing research activities and to discuss future contributions and directions within the AMMA programme. The location of Ouagadougou echoed the objective of raising awareness among regional organisations on the research issues tackled in AMMA.

The three main themes in the conference were:

1. Predictability of the West African monsoon weather, climate and impacts
2. Society-environment-climate interactions
3. West African monsoon system including atmospheric, oceanic, hydrology, and biosphere processes.

The conference was sponsored by AMMA projects and their funding organisations such as iLEAPS. Additional sponsoring is provided by IRD (Institut de Recherche pour le Développement, France), CNRM (Centre National de Recherches Météorologiques, France), START (Global Change System for Analysis, Research, and Training), and the IRD programme RIPECSA.

For more information, see Meetings/Ouagadougou 2009 at

<http://amma-international.org>

iLEAPS Early-Career Scientist Workshop,
University of Melbourne,
Melbourne, Australia,
20–22 August 2009



Melbourne, Australia, city center in August 2009.

49 early-career scientists from Europe, USA, Asia, and Australia took part in the 3-day Early-Career Scientist Workshop (ECSW) organised by iLEAPS and GEWEX and hosted by the University of Melbourne. The workshop was structured around comprehensive keynote presentations and related training and discussion sessions on the following topics:

Keynote sessions:

- Satellite sensors and remotely sensed products
- Local-to-regional and regional-to-global interfaces (upscaling/downscaling issues)
- Interaction of biogeochemical, water, and energy cycles
- Human-Earth system - a holistic picture
- Data-model assimilation
- Science-to-applications interface

Training and discussion sessions:

- Remote sensing applications - Data fusion in remote sensing applications
- Q & A session with experts
- Communication and presentation skills – preparing a 2-minute oral summary of posters
- Communicating science to media and policy makers



Photo by Marjut Nyman.

The participants presented their work in the form of posters accompanied by an optional 2-minute oral summary according to the guidelines taught in the Communication and presentation skills -training session.

The invited speakers and tutors were Will Steffen (ANU, Australia), Einar-Arne Herland (ESA, Italy), Ray Leuning (CSIRO, Australia), Mike Raupach (CSIRO, Australia), Toss Gascoigne and Cathy Sage (Econnect, Australia), Susannah Elliott (AUSSMC, Australia), Lindsay Hutley (CDU, Australia), and John Finnigan (CSIRO, Australia).

After the workshop, the participants drafted a white paper: "The new generation of 'Land-Atmosphere Exchange' scientists – An overview of the early-career scientists, and how their work will shape the direction of land-atmosphere science." The paper will be published in the next issue of the Newsletter.

Proceedings, poster presentations, and keynote speeches can be found at

www.ileaps.org/ecsw

**iLEAPS-GEWEX
Parallel Science Conferences,
Hotel Sofitel,
Melbourne,
24–28 August 2009**

The Sixth International Scientific Conference on the Global Energy and Water Cycle and the Second Integrated Land Ecosystem-Atmosphere Study (iLEAPS) Science Conference were held in parallel with separate and joint sessions at Hotel Sofitel in Melbourne. This venue provided an exciting platform for presenting and discussing the latest scientific developments in the area of water, energy and biogeochemical cycles. It also provided the opportunity for cross-fertilisation between the sciences represented by both GEWEX (Global Energy and Water Cycle Experiment) and iLEAPS in addressing present and future climate and global change challenges.

The parallel conferences featured three joint sessions on three common themes with keynote talks and oral and poster presentations:

- ❑ Land in the climate system
- ❑ Aerosol, cloud, precipitation, climate interactions
- ❑ Future generation of integrated observation and modelling systems.

The Second iLEAPS Science Conference focussed on interactions and feedbacks in the land-atmosphere system in order to improve our understanding of the processes and parameterisation of modelling in the form of four sessions:

1. Surface exchange processes from leaf level to Earth System scale
2. Progress in land-atmosphere interactions and climate change
3. The role of atmospheric boundary layer processes in modulating surface exchanges
4. Aerosols from the land surface and their interactions with the climate system

The next Newsletter will be a special issue on the iLEAPS sessions and the joint sessions with GEWEX. For more information and the abstracts, please see the conference website

http://gewex.org/2009gewex_ileaps_conf_info

**Arctic in Rapid Transition (ART)
Initiation Workshop,
International Arctic Research Centre,
University of Alaska,
Fairbanks, USA,
7–9 November 2009**

The International Conference on Arctic Research Planning (ICARP II) Marine Roundtable and the International Arctic Research Centre (IARC) organised this workshop to start the Arctic in Rapid Transition (ART) Initiative. The workshop was endorsed and sponsored by the International Arctic Science Committee (IASC) under the Arctic Ocean Sciences Board (AOSB) / Marine System.

The ultimate goal of the ART Initiation Workshop was to help develop a full science and implementation plan to further the goals of ART. The participants and several expert speakers from various disciplines such as oceanography, sea ice, biology, meteorology, geology/paleoceanography, and geochemistry discussed the key scientific questions outlined within the ART proposal. During a field trip, the participants were able to experience the Arctic in rapid transition for themselves.

The workshop broke into working groups centred on the identified three main components of ART:

- ❑ Sea ice variability
- ❑ Land-ocean transport processes
- ❑ Ecosystem responses

For more information and keynote speaker presentations, please see:

www.aosb.org/art

iLEAPS SCIENTIFIC STEERING COMMITTEE 2009

Meinrat O. Andreae (Co-Chair), Biogeochemistry Department, Max Planck Institute for Chemistry, Mainz, Germany

Pavel Kabat (Co-Chair), Earth System Science & Climate Change Group, Climate Change and Biosphere Centre, Wageningen University and Research Centre, Wageningen, Netherlands

Almut Arneth, Dept. Physical Geography and Ecosystems Analysis, Lund University, Lund, Sweden

Paulo Artaxo, Dept. Applied Physics, Institute of Physics, University of São Paulo, São Paulo, Brazil

Mary Anne Carroll, Dept. Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, Michigan, USA

Torben R. Christensen, Dept. Physical Geography and Ecosystems Analysis, Lund University, Lund, Sweden

John J. Finnigan, CSIRO Centre for Complex System Science, CSIRO Atmospheric, Canberra, Australia

Laurens Ganzeveld, Dept. Environmental Sciences, Earth System Sciences Group, Wageningen University and Research Centre, Wageningen, Netherlands

Sandy Harrison, School of Geographical Sciences, University of Bristol, Bristol, UK

Michael Keller, NEON Inc., Boulder, Colorado, USA

Markku Kulmala, Dept. Physics, University of Helsinki, Helsinki, Finland

Nathalie de Noblet-Ducoudré, Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Gif-sur-Yvette cedex, France

Andy Pitman, Climate Change Research Centre, The University of New South Wales, Sydney, Australia

Daniel Rosenfeld, The Hebrew University of Jerusalem, Jerusalem, Israel

Nobuko Saigusa, Office for Terrestrial Monitoring, Center for Global Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan

Sonia I. Seneviratne, Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

Chandra Venkataraman, Dept. Chemical Engineering, Indian Institute of Technology Bombay, Mumbai, India

Xiaodong Yan, Key Lab. Regional Climate-Environmental Research for Temperate East Asia (RCE-TEA), Institute of Atmospheric Physics, Chinese Academy of Science, Beijing, China

iLEAPS RECOGNIZED PROJECTS

