UK Arctic terrestrial research: achievements and priorities

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Strengths and Achievements

The UK terrestrial science community has a long and well established history of arctic research from early pioneering studies more than a century ago to development of a diverse research agenda, through individual projects, consortia and contributions to major international initiatives. Particular strengths include:

1) Early and continued development of field simulation experiments to determine the impacts of global change*.* These include some of the first experiments to assess the impacts of summer warming, precipitation and nutrient supply on arctic tundra[1], which combined with the UK's contribution to the International Tundra Experiment[2], successfully predicted changes in vegetation now being observed in parts of the Arctic[3]. Other internationally important studies include simulations of increased atmospheric CO_2 and UV-B radiation[4], acute and chronic atmospheric N deposition[5,6], and simulations of winter warming revealing considerable impacts from cold season climate change on vegetation and invertebrates [7]. All these studies have played a leading (and in many cases, globally unique) role in determining the impacts of global change on arctic ecosystems.

2) Arctic biogeochemistry, including critical plant-soil and plant-herbivore interactions, land-atmosphere coupling and feedbacks to climate. UK terrestrial science has driven major initiatives to quantify the carbon stored by arctic landscapes and how this varies with climate, vegetation type, hydrology, topography and snow regime[4,8-11]. Gradient and transect studies have assessed the response of the forest-tundra ecotone to global change (including impacts on CO_2 and CH_4 fluxes) and the role of plant community composition in regulating soil C storage and fluxes, including the potential for enhanced tundra soil organic matter decomposition and loss of tundra soil carbon stocks caused by treeline advance[8,10]. Further studies have demonstrated the importance of trophic interactions, particularly the influence of fauna (including extensive studies investigating the impacts of invertebrates and geese) in influencing tundra biogeochemical cycling[12].

3) Biogeochemistry of rivers and ice-bound habitats. UK science has advanced understanding of the controls on green house gas release from northern peatland catchments and fluvial gas fluxes. Advances are being made in the biogeochemistry of ice-bound habitats, nutrient mass balance observations through snow-ice systems and the exploration of microbial ecosystems within and beneath ice[13]. Further, interdisciplinary approaches are being used to understand the role of glacial, snowmelt and groundwater water sources in driving river physicochemical habitats that determine the structure and function of biotic communities[14].

4) Snow regime impacts on arctic ecosystems, surface and boundary layer processes. Advances include the combination of landscape and manipulation experiments to assess the impacts of changing snow cover on soil biogeochemistry, hydrology, invertebrate communities, plant productivity, trace gas flux and surface energy balance that highlight the importance of snow regime in mediating annual C balance[7,9,15]. Furthermore, empirical data have been used to understand and model the influence of snow in arctic surface and boundary layer processes (including snow-vegetation-atmosphere transfer) and have been combined with remote sensing of snow properties for ground truthing and modelling[15].

5) Modelling, model-data fusion and upscaling process knowledge. Major strengths include remote sensing and aircraft capability to allow upscaling of field data and their incorporation into modelling: this includes use of field data to inform JULES (the land-surface model in the Hadley Centre GCM) [8,16]. Furthermore, field data have elucidated important emergent ecosystem properties that significantly simplify upscaling and modelling of tundra C sequestration and stocks, and provide opportunities for assessment of C stocks from remote sensing[8,17]. Such work includes development of a single model that allows estimates of net CO_2 flux using leaf area and elucidation of the scale-invariance of leaf area-reflectance relationships, providing a basis for using remotely sensed reflectance data to upscale carbon fluxes across the Arctic[17].

6) Palaeoenvironmental research. UK science has driven major developments in palaeoenvironmental research using archives such as lake sediments and peat bogs and a wide variety of biotic and abiotic proxies. Major developments include quantitative reconstruction of past environments and environmental change on decadal to millennial time-scales, changes in hydrology, UV-B radiation, impacts of recent warming on lake systems and pollution loads, consequences for ecosystem carbon balance and understanding past and present distributions of taxa[18-21]. New techniques using ancient DNA are also being pioneered which promise insights into past population dynamics and changes in genetic diversity, ecology and the composition of a broad range of biotic communities[22,23].

Addressing research priorities in arctic science

The combination of strengths, skills and approaches outlined above places the UK arctic terrestrial community in a strong position to address critical questions about the past, present and future state of the Arctic. This is enhanced by a broad geographical spread of research (including North America, Europe and Russia) that enhances UK terrestrial science's contribution to a circumpolar understanding of the Arctic. The impact of the community to date is clearly evident with nearly 350 arctic publications in peer reviewed journals in the past 10 years (and approaching 500 since 1990)[24]. Furthermore, UK terrestrial scientists play an important role in providing leadership of major research initiatives [for example, ABACUS (NERC-IPY, £1.7M), NSINK (EU, €2M), UVECOS (EU, €1.2M), MultiArc (EU, €1M)], they provide significant contributions to international programmes [for example, CARBO-North, SPICE, TUNDRA, DART, FRAGILE] and play leading roles in international assessments [including IPCC, ACIA, SWIPA and the Millennium Ecosystem Assessment].

Research priorities in a rapidly changing terrestrial arctic.

The terrestrial Arctic is a key component of the Earth system and is currently undergoing some of the *most rapid change in climate* of any region, with greatest warming occurring over its terrestrial domain. Critically, such change will have major implications for climate in other regions *including the UK*. Vast stores of carbon within predominantly frozen soils are at risk of release from soil warming and permafrost thaw. Warming and drying of tundra soils are already causing many regions to shift from carbon sink to source. Changes in snow cover (reduction) and vegetation (expansion) are already clearly apparent and will have major further impacts on energy balance, with reduced albedo providing additional positive feedback to global climate. Changes in vegetation will have further, yet still poorly understood, effects on carbon balance. Displacement of tundra by forest is predicted to prime soil organic matter decomposition, enhancing efflux of carbon from soils. Greater frequency of extreme events, including fires, pest outbreaks, disease and extreme climatic events are predicted and atmospheric nitrogen deposition in arctic regions continues to rise. Reliable estimates of the direction and rates of change of key processes are essential to efforts to model the earth system. Given the considerable global change in the terrestrial arctic, the clear changes already taking place and the major impact these changes will have for global climate, there has never been a more urgent need to understand the consequences of global change for the terrestrial Arctic. Major priority areas for research are to:

1. **Quantify the size of arctic terrestrial carbon stocks and their vulnerability to climate change, including**
   - better understanding of the thresholds and non-linearity of responses to climate change,
   - assessment of the risks posed by extreme events as well as gradual climate change.
2. **Assess how fast and to what extent green house gas (GHG) fluxes are changing in the Arctic, including**
   - quantification of the balance of GHG fluxes within terrestrial systems,
   - use of integrated landscape scale approaches, including the role of freshwater ecosystems and their sensitivity to change.
3. **Quantify feedbacks to climate and impacts on marine environments.**
4. **Assess past, present and future climate change impacts on biodiversity and ecosystem function, including**
   - consequences of these changes for biogeochemical cycling, particularly carbon stocks and fluxes,
   - better understanding of the role of ecosystem resilience, invasive species and trophic interactions.
5. **Determine the role of nitrogen and increases in N inputs in mediating changes in the above (1-4).**

References to example publications and research initiatives: **[1]** Arctic Special Topic (NERC); Press et al. (1998) *J. Ecol.* 86,315; Strathdee & Bale (1993) *Polar Biol.* 13,577; **[2]** Walker et al. (2006) *PNAS* 103,1342; **[3]** Sturm et al. (2001) Nature 411,546; **[4]** UVECOS (EU, UK lead), Johnson et al. (2002) *Nature*, 416,82; **[5]** Gordon et al. (2001) *New Phyt*. 149,461; **[6]** NSINK (EU, UK lead); **[7]** Bokhorst et al. (2009) *J. Ecol.* 97,1408; Coulson et al. (2000) *Ecography* 23,299; **[8]** ABACUS (NERC-IPY); **[9]** STEPPS (NERC); **[10]** DART (EU); **[11]** MultiArc (EU, UK lead); **[12]** FRAGILE (EU); van der Wal et al. (2007) *GCB*, 13,539; Hodkinson & Wookey (1999) *App. Soil Ecol.* 11,111; **[13]** Hodson et al. (2008) *Ecol. Monogr.* 78,41; **[14]** Brown et al. (2009) *Freshwater Biol.* in press; **[15]** Essery et al. (2006) *Hydrol. Proc.* 20,953; Essery & Pomeroy (2004) *J. Hydromet.* 5,735; **[16]** QUEST, Blyth et al. (2009) *J.Hydromet.* in press; **[17]** Street et al., (2007) *J. Ecol.* 95,139; Williams et al. (2008) *GCB* 14,1517; **[18]** Anderson et al. (2009) *GCB* in press; **[19]** Solovieva et al. (2008) *Palaeogeo. Palaeoclim. Palaeoecol.* 259,96; **[20]** Muir & Rose (2004) *DEPR* 8; **[21]** Smol et al. (2005) *PNAS* 102,4397; **[22]** ECOCHANGE (EU); QUEST (NERC) **[23]** Barnes et al. (2002) Science 295:2267; Shapiro et al. (2004) Science 306:1561; **[24]** by those contributing to the Arctic terrestrial group meeting, University of Sheffield, 13/11/09.

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