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1. Title

Vulnerability of carbon in permafrost:

Pool size and potential effects on the climate system

2. Short Title - two or three words for use as a project name (25 characters max)

Carbon vulnerability

3. Name and complete contact information
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4. Summary - appropriate for public distribution on NCEAS' web site

Ecosystem responses that cause carbon loss to the atmosphere in a warming climate could greatly accelerate climate change during this century. Potentially vulnerable carbon pools that currently contain hundreds of billion tons of carbon could be destabilized through global warming and land use change. Some of the most vulnerable pools on land and oceans are: soil carbon in permafrost, soil carbon in high and low-latitude wetlands, biomass-carbon in forests, methane hydrates in the coastal zone, and ocean carbon concentrated by the biological pump. The risk of large losses from these pools is not well known, and is not included in most climate simulations. Preliminary analyses indicate a risk over the coming century that may be larger than 200 ppm of atmospheric CO₂, rivaling the expected release from fossil fuel combustion. This proposal will quantify the carbon content of the vulnerable pools in permafrost soils and analyze the risk of large releases of carbon from these pools over this century.

5. Problem Statement

Recent modeling simulations have shown the major potential role of previously undocumented positive feedbacks between warming and the terrestrial C cycle in driving climate change during the 21st Century (Cox et al. 2000; Dufresne et al. 2002; Friedlingstein et al. 2003).

The findings showed that CO₂ releases stimulated by warming accelerate warming and further CO₂ releases well above what is currently predicted by the IPCC (2001). In these studies, the loss of C from vulnerable pools were tropical forest by fire and soil C by increased decomposition. The experiments to date, however, are too limited to support an accurate quantification of these positive feedbacks, but the range of the results highlights the importance of further progress. The behavior of two models of comparable sophistication is so different that, with similar forcing, they differ in atmospheric CO₂ in 2100 by 200 ppm.

A literature analyses documents the existence of a number of vulnerable C pools both on land and in the oceans (Fig. 1), with the potential for C release to the atmosphere on the order of several hundred Pg during this century (Gruber et al. 2004). Such a massive release of greenhouse gases to the atmosphere would result in higher concentrations of atmospheric CO₂, accelerating climate warming, and potentially stimulating even greater losses of carbon from vulnerable pools.

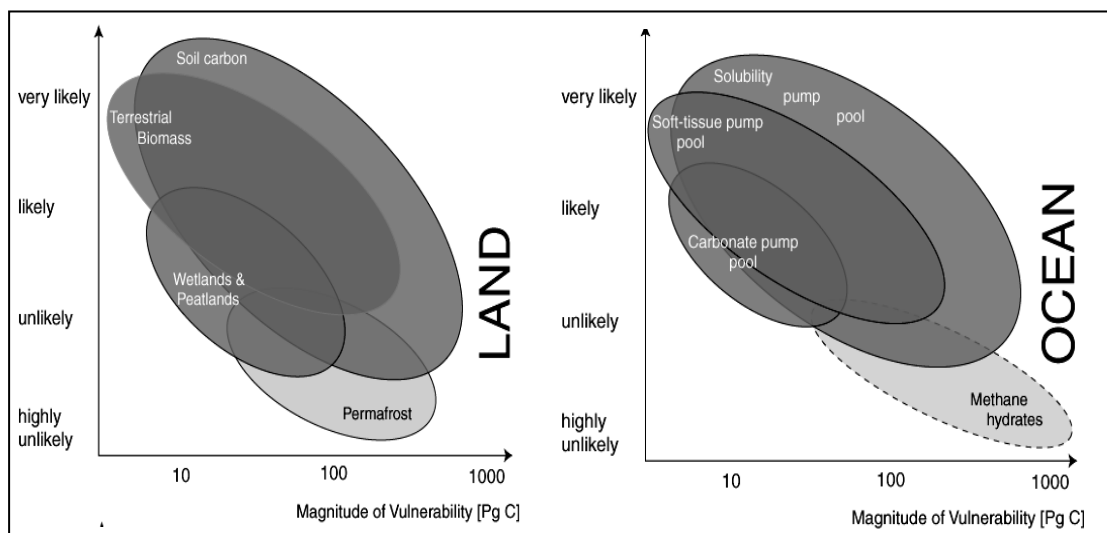


Figure 1. Magnitude and Vulnerability of C pools on land and oceans (Gruber et al. 2004).

Four mechanisms especially warrant intensive study (Gruber et al. 2004). The first of these is the respiration of C currently locked in permanently frozen soils. GCM simulations indicate that up to 25% the permafrost in the Northern Hemisphere may disappear over the next century. Since these soils contain large quantities of C (Michaelson et al. 1996), and since much of the C is relatively labile once thawed, potential releases over a century could be in the range of several hundreds of Pg C (Gruber et al. 2004). These carbon stocks will be the focus of the proposed NCEAS working group.

Over the next few years, we hope, under the umbrella of the Global Carbon Project, to use a variety of funding and organizational mechanisms to synthesize information on other vulnerable pools, including the following. Wetland soils contain vast quantities of C that is subject to rapid decomposition when dry and aerated. Drying can even allow wildfires, such as those that released an estimated 200 Tg C in the 1997 fires in Borneo (Page et al. 2002). Drying wetland soils might result in a decrease in methane emissions, along with an increase in CO₂ emissions, requiring a careful analysis of overall greenhouse forcing (Manne and Richels 2004).

Large-scale wildfire, especially in tropical and boreal forest ecosystems has the potential for massive C releases in the future (Gruber et al. 2004). Climate changes in both kinds of ecosystems could push large areas past a threshold where they are dry enough to support large wildfires, and a fundamental change in the fire regime could effectively eliminate large areas of forest.

A final set of pools is in the oceans. One very large pool is the vast quantities of methane, exceeding all known fossil fuel reserves, that exist in the form of methane hydrates. These occur primarily under continental shelf sediments around the world, and in the Arctic permafrost. Geologic evidence suggests massive releases of methane from the ancient sea floor, associated with episodes of global warming (Dickens et al, 1997). Could such a large scale release happen over the next hundred years? A second area of potentially important ocean vulnerability concerns the incremental organic and inorganic carbon that depend on the biological pump. Widespread changes in the structure of ocean biological communities could fundamentally change the operation of the biological pump (Gruber et al. 2004).

None of these four mechanisms with their associated size of C pools is thoroughly addressed in current ecosystem or climate models. As a consequence, it is not yet feasible to estimate either the probability of the changes or the likely C emissions. Still, ignoring the potential for these large releases is not responsible, and the vulnerability of the climate system to them should be explored.

At present, there is no comprehensive and up-to-date synthesis of the carbon content in frozen soils despite the availability of a number of regional assessments for parts of the world and of the soil profile, nor a synthesis exist of the acknowledge accumulated over this past decade on carbon dynamics in thawing permafrost; Nor is there an assessment of their possible feedbacks to global warming. The biggest obstacles to progress are the lack of (i) spatially explicit data on the sizes of the pool, and (ii) credible algorithms for simulating the vulnerability of this pool to climate change.

The goals of this proposal are to:

- Compile a catalog of vulnerable C pools in frozen ground and their global distribution.
- Quantify the extent of these vulnerable pools and their C content.
- Assess the processes affecting the balance and release of C, including the identification of “thresholds” that push the system rapidly to dangerous climate change.
- Test algorithms for integrating the carbon dynamics of permafrost pools in terrestrial biogeochemical models and coupled climate/carbon models.
- Provide algorithms for other modeling efforts that will address the climate/carbon and other climate/ecosystem feedbacks.

References

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6. Names of Participants

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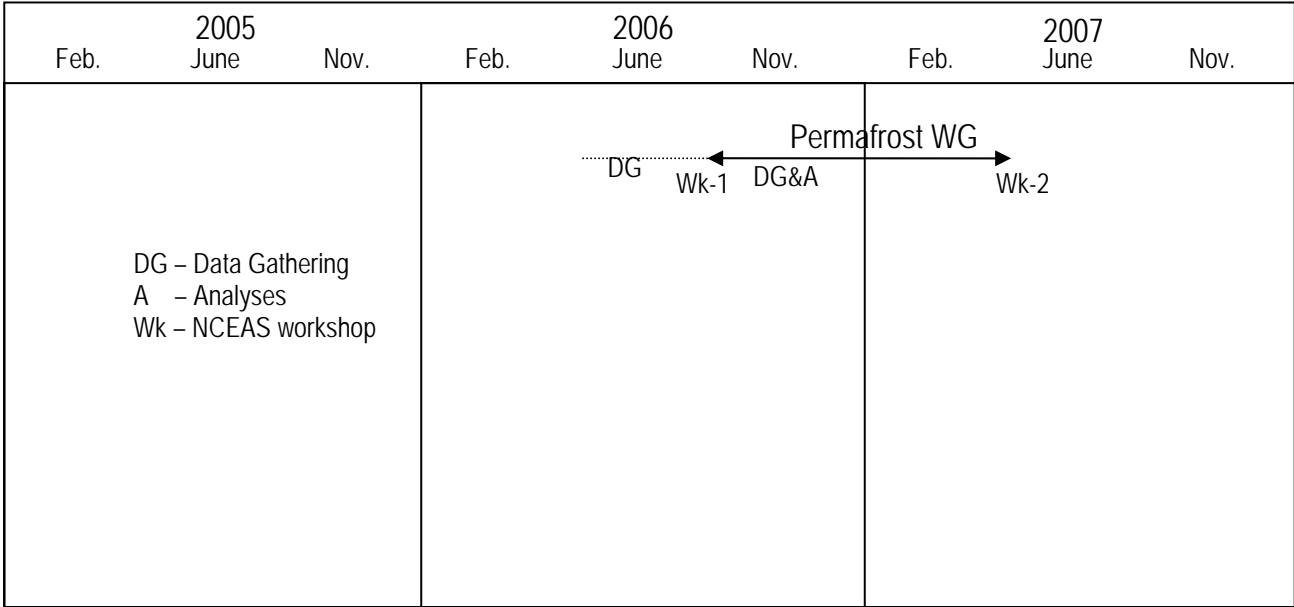
7. Rationale for NCEAS support

This activity requires an interdisciplinary effort, including data gathering as well as synthesis and analysis. Its success depends on assembling the right group, including experts on permafrost dynamics, C data collection, ecosystem modeling, and climate modeling who can interact with each other throughout the process of data gathering analysis and synthesis. The reason climate models are not able to deal with a number of potentially critical processes is in large part because the climate modelers and the ecosystem-process research community have not interacted effectively in the past. This activity and others related to it will help address this issue.

8. Proposed Activities

We propose 2 working group meetings in 2006-07. The WG will be made up of approximately 8 experts on permafrost, 1-2 ecosystem modelers, and 1-2 climate modelers. Before of the first workshop, the WG will be charged with collecting data and information on processes relevant to the analyses of extension, C content, and vulnerability of the C to be released. The WGs will continue their analyses and data gathering after the first workshop for most of a year before they meet for the second time. Shortly after the second workshop, the group will deliver the state-of-the-art analyses on each of the C pools.

Figure 2. Timetable



9. Anticipated Results and Beneficiaries

We believe that carbon vulnerability is one of the key unknowns in climate change. If the vulnerability is great, the task of mitigating or adapting to climate change becomes much more complex, and the priority on avoiding climate changes sufficient to drive large carbon losses becomes much greater. The results of this activity will be critical in re-thinking the feedbacks of greenhouses gas emissions on the climate system. This work may have major policy implications.

The major products of this activity, as per the goals established in section 5, will be:

- An overall synthesis paper, hopefully for a high-impact journal like Science/Nature
- A peer-reviewed synthesis paper, or potentially a series of papers on different regions or ecosystem types
- A new updated and spatially explicit database on carbon content in frozen soils world wide (with a peer reviewed paper describing it).
- A peer review synthesis paper on processes controlling carbon dynamics in thawing permafrost.
- Improved climate models and recommendations for improving their capacity to deal with permafrost-carbon feedbacks.

This activity will be a contribution to the scientific agenda of the Global Carbon Project (GCP 2003*), a project established by IGBP, IHDP, and WCRP to deal with highly interdisciplinary and complex problems of the carbon-climate system. The GCP will endorse and support this activity by providing:

- administrative support from the International Project Office based in Canberra, Australia.
- web support and product dissemination over its global network.
- expertise and funding for the executive summary brochure for policy makers and high education.

This project will also contribute to the research agendas of the Climate and Cryosphere project (CliC) of WCRP and the International Permafrost Association.

(*) GCP. 2003. Global Carbon Project: Science framework and implementation. Canadell JG, Dickinson R, Hibbard K, Raupach M, Young O (eds.) Earth System Science Partnership Report No. 1; GCP Report No. 1, 69pp, Canberra.

Downloadable from www.globalcarbonproject.org/science_plan_and_implementation.htm
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