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Introduction to the Alaska carbon cycle invited feature

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Ongoing warming in northern high latitude ecosystems such as those in Alaska has the potential to release carbon to the atmosphere through (1) exposing and mobilizing the large quantity of organic carbon stored in upland soils and permafrost, wetlands, and surface waters, (2) emissions associated with potentially more frequent and severe fires, and (3) greater methane emissions. However, there are several possible mechanisms that could counter this carbon release including enhanced photosynthetic uptake of carbon dioxide (from longer and warmer growing seasons, increased soil nitrogen availability, rising atmospheric CO_2) and a switch from more flammable conifer forest to less flammable deciduous forest (feedbacks between ecosystem structure/function and fire regime). The issue of how and where Alaska carbon storage is likely to respond in a changing climate is important to carbon management efforts at the national scale, as Alaska contains one-fifth of the area of the continental United States and stores approximately one-half of the country's land ecosystem carbon. Information about the amount and fate of carbon from Alaska could have national policy implications by offsetting gains in or adding to carbon sequestration elsewhere. Also, knowledge of responses of carbon in Alaska may help inform expectations about responses of carbon from northern high latitude ecosystems in Canada and Eurasia.

This Invited Feature takes the step to better understand the potential implications of carbon responses in Alaska for national climate and carbon management policies. The papers of this Invited Feature report on the effort by the U.S. Geological Survey, in collaboration with the U.S. Forest Service and university scientists, to conduct a comprehensive assessment of historical and projected carbon balance for Alaska as mandated by the Energy Independence and Security Act of 2007 (U.S. EPA 2007).

This assessment of carbon dynamics in Alaska breaks ground by combining (1) syntheses of soil, vegetation, and surface water carbon stocks and fluxes in Alaska and (2) state-of-the-art models of fire dynamics, vegetation change, forest management, permafrost soil dynamics, and upland, wetland, and surface water ecosystem carbon dynamics. This set of approaches provides information on (1) feedbacks between ecosystem structure/function and fire regime, (2) the fate of deep carbon in permafrost and soils, and (3) the mass balance of carbon in and across uplands, wetlands, and surface waters in Alaska with a nominal resolution of 1 km^2. The analyses within the assessment are also organized to make the information available to major management consortia in Alaska, i.e., the Arctic, Western Alaska, Northwest Boreal, and the North Pacific Landscape Conservation Cooperatives, as well as other regional activities to understand and communicate the effects of climate change on resource management in Alaska (e.g., the USGS Alaska Climate Science Center and the newly formed USDA Northwest Climate Hub). The information from this integrated assessment is relevant to the climate policy community and to the communities responsible for management of carbon at local, regional, national, and international scales.

The approach taken in this Invited Feature is to provide analyses for Alaska of (1) the drivers (i.e., climate, fire, and permafrost dynamics) of historical (1950–2009) and projected (2010–2099) carbon cycle dynamics (Pastick et al. 2017), (2) the responses of historical and projected vegetation and soil organic carbon stocks and fluxes to these drivers in upland (Genet et al. 2018) and (3) wetland ecosystems (Lyu et al. 2018), (4) and river transport of dissolved organic and inorganic carbon, the emissions of carbon dioxide and methane from inland water surfaces, and the burial of carbon in lake sediments (Stackpoole et al. 2017). Finally, the paper by McGuire et al. (2018) provides an overall synthesis of historical and projected carbon balance in Alaska's landscapes and discusses carbon policy and management implications.

The analyses among the papers in the Invited Feature provide quantitative estimates on the effects of climate change on drivers and carbon (C) dynamics. The analysis of drivers by Pastick et al. (2017) estimates that climate change would reduce the current proportion of near-surface permafrost extent in Alaska by 9% to 74% by the end of the 21st century, and that fire activity would substantially increase in the boreal forest of Alaska. Genet et al. (2018) estimate that upland ecosystems of Alaska currently store ~50 Pg (10^{15} g) C, gained ~3 Tg (10^{12} g) C/yr in the historical period, and could increase in carbon storage by 3% to 12% by 2100. Lyu et al. (2018) estimate that wetland ecosystems of Alaska lost ~3 Tg C/yr in the historical period, but could increase in carbon storage by 2–4 Tg C/yr during the projection period.

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However, Lyu et al. (2018) note that methane emissions from wetlands could increase by a mean of ~50% across the climate projections considered. Stackpoole et al. (2017) estimate that total aquatic C flux for Alaska during the historical period was 41 Tg C/yr, with 18 for river lateral export, 17 for river carbon dioxide emissions, and eight for lake carbon dioxide emissions minus two for burial in lake sediments. The synthesis of McGuire et al. (2018) estimates that carbon storage of upland and wetland ecosystems of Alaska will increase by 22–70 Tg C/yr during the projection period, primarily because of net primary production increases of 10% to 30% associated with responses to rising atmospheric carbon dioxide, increased nitrogen cycling, and longer growing seasons. However, sensitivity analyses suggest that projected carbon sequestration in upland and wetland ecosystems of Alaska would be rather transient in nature and may not be sustained beyond the end of this century.

Taken as a whole, the set of papers in the Invited Feature provide a comprehensive view of a critical region, and one that could be a model for other regions within the United States and globally. Although there are substantial uncertainties in the analyses, the analyses themselves represent state-of-the-art science, and this assessment provides information for developing priorities to reduce uncertainties that should improve future assessments.

For example, future assessments should integrate the carbon dynamics of upland and wetland ecosystems with inland aquatic ecosystems. Also, it is important to model future CH_4 emissions of lakes, which were not estimated in this assessment. In addition, the effects of other disturbances besides fire, such as those of insect and abrupt thaw disturbance, should be taken into account by future assessments. We also recommend that future assessments extend the time period of analysis to the year 2300 so that transitional carbon dynamics associated with permafrost thaw and photosynthetic saturation to elevated atmospheric CO_2 have enough time to become manifest. Finally, it would be useful for future assessments to more comprehensively analyze the societal impacts of climate change in Alaska.

Note that McGuire and Zhu were organizers of the invited feature, Birdsey reviewed the associated U.S. Geological Survey report, and Pan and Schimel were guest editors of the Invited Feature.

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