Interrelation of Global Climate and the Response of Oceanic Hydrate Accumulations

Progress Report

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NETL Manager: Skip Pratt

Principal Investigator: George J. Moridis, gjmoridis@lbl.gov, (510) 486-4746

Task Progress

Task 09-1: Completion of the Reactive Transport Enhancements to POP

(Finished at the end of 2009/beginning of 2010) The team at LANL developed a marine methane cycle simulation capability within POP. A full biogeochemical oxidation scheme was implemented such that molecular oxygen is consumed within the POP ecodynamics module while dissolved inorganic carbon is added to the water column with attendant affects on seawater acidity. Results using this code are discussed below.

Task 09-2: Completion of Code Integration and Testing

(Finished at the end of 2009/beginning of 2010) The coupled use of TOUGH+HYDRATE and C.CANDI determined that the ability of sediment biogeochemical processes to mitigate methane release is highly limited, and that large-scale oxidation-reduction of methane to stable carbonates can only occur under a narrow set of conditions. This suggested that the focus of methane chemistry must be in the water column.

Task 09-3: Completion of Studies of Greenhouse Gas Releases at the Ocean Floor on Limited Spatial Scales

Task 10-1: Expansion to Medium-Scale, Fully-Coupled Simulations of Releases of Hydrate-Originating Greenhouse Gases

The ocean model component of our team has analyzed results from the introduction of LBL sediment interface fluxes into the Parallel Ocean Program (POP). Fully dynamic chemistry-transport simulations were conducted representing intense methane release into the Arctic regime during the period of early global warming. Marine methane consuming bacteria will oxidize the molecule in large part. This process has the potential to deplete oxygen and raise pH in poorly ventilated deepwater masses, and to deplete nutrients such as the trace metals and nitrogen in many locations. Reagent restrictions may allow the undersea gas distributions to expand and approach the atmosphere, where methane acts as an ultra-strong greenhouse forcer. For aqueous release (full dissolution of the methane), much of the effluent, however, remains below the ocean mixed layer while circuiting the central Arctic and then subducting into the abyssal Atlantic. The portion of methane rising from sea floor as bubbles remains a large uncertainty (as plumes would transport addition methane into the mixed layer), so adding bubble-plume parameterizations to POP is underway.

These outcomes were described in a paper recently published in *Geophysical Research Letters*, and also as a longer exposition currently accepted and in press at the parent publication *Journal of Geophysical Research* (both submitted during the Spring reporting period). These papers review the scientific background of ocean methane processes (derived from diverse sources), describe a new synthesis of knowledge about methane and methanotrophs in the water column, and present the models of methane injection into a biologically active ocean environment. The results show that that in different localities any of the major oxidants/nutrients specific to the methanotrophic metabolism may turn out to be limiting: oxygen, nitrate, copper or iron. These resource limitations may hinder the ability of microorganisms to consume the released methane, such that previous assumptions in the literature about "99% consumption" of all methane (derived from observations of established methane seep systems at Coal Oil Point and Cascadia) are incorrect. The geochemistry of the water column is clearly altered, other organisms will not have the material available to use, and as such even localized releases may have severe ecological consequences. These papers should be important early contributions to the growing area of methane and the environment.

Published/In Press:

1. Elliott, S.M., Maltrud, M., Reagan, M.T., Moridis, G.J., Cameron-Smith, P.J., "Marine Methane Cycle Simulations for the Period of Early Global Warming," *J. Geophysical Res. Biogeo.*, doi: 10.1029/2010JG001300, in press, 2010.
2. Elliott, S.M., Reagan, M.T., Moridis, G.J., Cameron-Smith, P.J., "Geochemistry of Clathrate-Derived Methane in Arctic Ocean Waters," LBNL-3389E, *Geophys. Res. Lett.*, 37, L12607, doi:10.1029/2010GL043369, 2010.

Work on Task 09-3 was completed on schedule, setting up the continuation and expansion of the work in Task 10-1. The simulation work has been expanded to large-scale 2-D simulation of dissociating hydrates along the arctic continental margin, with the efforts beginning with the system discovered by Westbrook and colleagues off Spitsbergen. Current simulations are moving to other areas of interest, including the Sea of Okhotsk, New Zealand, and locations in the Gulf of Mexico. Geomechanical consequences are being considered for the first time. The LBNL team is working directly with the LANL team to assess the ocean biogeochemical effects of each of these new scenarios on a basin/regional scale.

Results in each case show that methane can be released in gaseous form, driven by dissociating hydrate alone, for systems with sufficient permeability (typically 1mD or greater) and capillary properties that allow gas migration via buoyancy. The results also show the emergence of narrow methane gas plumes at the seafloor at the landward limit of the receding GHSZ—a result that closely resembles the system observed by Westbrook, strengthening the possible connection between the plumes and hydrates. A conference paper on these simulations and a letter to *Geophysical Research Letters* were published in 2009. A full-length paper on the behavior of sloping systems, including multiple temperature scenarios, slope angles, sediment properties, and a sensitivity analysis, has been submitted to the *Journal of Geophysical Research*.

Submitted:

3. Reagan, M.T., Moridis, G.J., Elliott, S.M., Maltrud, M., "Oceanic Gas Hydrate Dissociation Along the Arctic Continental Slope" for *J. Geophys. Res. Oceans*.

Task 10-3: Communications and Technology Transfer

Activities in this task are in progress and on schedule. The three papers published/submitted are listed above. In addition, the work performed in this project has once again been highlighted in the scientific press:

1. "Getting to the Bottom of Methane," *NPR Living On Earth*, March 12, 2010.

2. "'Arctic Armageddon' Needs More Science, Less Hype," *Science*, 329, 5992, 620-621, doi: 10.1126/science.329.5992.620.

3. Reagan, M.T., Moridis, G.J., Elliott, S.M., Maltrud, M., "Dissociation of Oceanic Hydrates in Response to Climate Change and the Biogeochemical Consequences," *Fire in the Ice*, DOE Methane Hydrates Program.

The following presentations have been made in 2010 regarding the work performed in the previous tasks:

1. "Oceanic Hydrates, Methane, Ocean Chemistry, and Climate," Gordon Research Conference on Natural Gas Hydrates, Colby College, Waterville, ME, 6-10 June 2010.

2. "Arctic Methane, Hydrates, and Global Climate," (invited) DOE Laboratory Energy R&D Working Group Meeting, Washington, DC, 17 Feb 2010.

3. "Interrelation of Global Climate and the Response of Oceanic Hydrate Accumulations," NETL Methane Hydrates Program Symposium, Atlanta, GA, 25-29 January 2010.

This work has also been highlighted in internal seminars at LBNL:

1. "Arctic Methane, Hydrates, and Global Climate," Environmental and Energy Technology Division Seminar, 17 March 2010.

2. "Climate Change and the Response of Oceanic Hydrate Accumulations," ESD Town

Hall, February 2010.