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Permafrost Melting and Stability of Offshore Methane Hydrates Subject to Global Warming

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ABSTRACT

Recently proposed global warming scenarios are employed to determine the effect of a wide range of anticipated global temperature rises on the stability of: (a) onshore permafrost; and (b) methane gas hydrates located below the ocean floor in deep water. Temperature profiles, the time required for the onset of hydrate decomposition and the rate of permafrost melting are computed. It is found that while permafrost decomposition due to global warming is feasible, decomposition of the suboceanic hydrates is not likely in the foreseeable future.

NOMENCLATURE

G : methane-rich gas phase
H : hydrate
I : ice
k : thermal conductivity (W/m K)
L : liquid water rich phase
T : temperature (K)
t : time (years)
t^* : critical time for onset of hydrate decomposition (years)
x : depth in earth (m)
xh : depth at which top of hydrate stability zone is located
Xp : depth of permafrost/sediment phase change interface
α : thermal diffusivity (m^2/s)
β : global warming scenario (°C/year)
γ : geothermal or hydrothermal gradient (°C/m)
λ^{diss} : heat of fusion for water (J/Kg)
ρ : density of medium (Kg/m3)
ε : soil water saturation

INTRODUCTION

The increase in the concentration of trace atmospheric gases (TAG) in the atmosphere (Brackley, 1990; Crutzen, 1991) has caused the current concern that the global climate will undergo drastic changes. The physics of the phenomenon known as the greenhouse effect are now well validated (Taylor, 1991). This phenomenon is responsible for sustaining the current average temperature on the surface of the earth. The temperature would be 33 K lower in the absence of the greenhouse effect. The increased concentration of TAG will disturb this climate equilibrium because more infrared energy will be trapped and subsequently reradiated causing global warming near the earth's surface. Although the magnitude of the global warming can not be easily calculated, three possible global temperature rise scenarios for the next century were suggested by a group of scientists (Schneider, 1990), namely a catastrophic (0.08°C/year), a moderate (0.03°C/year) and a low impact annual temperature rise (0.006°C/year) scenario.

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Among the consequences of this global temperature rise is the possible decomposition of the earth's methane gas hydrates. Because the quantity of methane hydrates in the earth is enormous (Kvenvolden, 1988a; Sloan, 1990), decomposition of the in-situ hydrates could be a significant source of methane in the atmosphere. Methane is a strong greenhouse gas and could thus cause enhancement of the greenhouse effect.

The relationship between global warming and the stability of the gas hydrates in the earth's crust has already been investigated (Bell, 1982; Revelle, 1983; Kvenvolden, 1988b). These studies were based on the impact of steep changes in the global temperature on the methane hydrate stability zones. Lachenbruch and Marshall (1986) and MacDonald (1990) employed the heat conduction equation without phase change to compute temperature profiles in the earth. The stability of the methane hydrate in the hydrate stability zone was examined by a superposition of the temperature profile on the temperature-depth (geothermal gradient) diagram. Englezos (1992) also used the heat conduction equation without phase change and examined the impact of the three recently proposed global warming scenarios on the stability of hydrates in the Arctic.

The above studies considered the earth's zone above the hydrate to be a single medium. This assumption allows an analytical solution of the heat conduction equation without phase change. Hydrates, however, do not usually occupy the entire zone of hydrate stability, but they are often assumed to be concentrated in a layer at the base of the hydrate stability zone (Hyndman and Davis, 1992). Permafrost melting at the surface of the earth should also be taken into account. Furthermore, methane hydrate decomposition is not instantaneous, hence, simple superposition of the temperature profiles is an oversimplification (Englezos, 1992).

Hatzikiriakos and Englezos (1993) took these considerations into account and developed a mathematical model that computes the temperature profile in the earth's crust which consists of several media with different thermal and geological properties. They also considered the effect of permafrost phase change whenever it is thermodynamically feasible. Based on the methane-water partial phase diagram in the hydrating region, they introduced a variable which expresses the driving force for hydrate decomposition. The critical time for the onset of methane hydrate decomposition due to global warming was thus calculated for hydrate reservoirs beneath single or composite media with and without permafrost phase change. The study examined the stability of onshore hydrates.

The computation of the effect of global warming on the temper-