The Role of Natural Wetlands in the Global Methane Cycle

Methane (CH₄) is the most important greenhouse gas after water vapor and carbon dioxide (CO₂), and wetlands represent its largest natural source. But the high spatial and temporal variability of CH₄ emissions from natural wetlands combined with patchy and incomplete information on global wetland distribution makes them especially difficult to quantify. CH₄ from natural wetlands still has the largest uncertainty of any CH₄ source. This is of concern because projections for the future suggest a rise in CH₄ emissions and thus a positive feedback in climate change.

We also know from ice cores that atmospheric CH₄ concentration has varied by a factor of 2, at orbital and suborbital frequencies, during the past 400,000 years. The causes of these variations are largely unknown, but it is likely that variations in wetland extent and productivity due to changes in glaciation, sea level, atmospheric CO₂ concentration, and climate played a part. Other mechanisms, including changes in the oxidation capacity of the atmosphere and pulsed releases from marine and terrestrial gas hydrates, may have contributed as well. None of these mechanisms is adequately quantified.

A workshop held near Bristol, U.K. dealt with observations, process studies, and modeling of CH₄ emissions from natural wetlands. Over 40 scientists from a range of disciplines attended. This was the first international workshop sponsored by QUEST (Quantifying and Understanding the Earth System), a program of the U.K. Natural Environment Research Council (NERC). One of QUEST's themes (see http://quest.bris.ac.uk for themes and workshop participants) is the contemporary carbon cycle and its interactions with climate and atmospheric chemistry; another is the natural regulation of atmospheric composition on glacial-interglacial timescales.

Understanding and modeling the natural variability of CH₄ emissions from wetlands at large spatial scales is an important crosscutting topic for QUEST.

What is Known About Controls on CH₄ Emissions

Under anoxic soil conditions, methanogenic archaea produce CH₄ principally by the fermentation of acetate and/or oxidation of hydrogen using CO₂ as electron acceptor. Much of the CH₄ produced is subsequently oxidized by methanotrophic bacteria. The rest is transported to the atmosphere via bubbling and diffusion, or escapes through the aerenchyma of certain vascular plants. The water table position determines the depth of maximum CH₄ production. Temperature influences the rates of CH₄ production and oxidation and also the net primary production (NPP), and thereby the quality and quantity of the organic substrate for CH₄ production. These processes have been relatively well studied in temperate and boreal bogs and fens—far less so in tropical wetlands.

Workshop participants demonstrated that process-based models reproduce daily CH₄ emissions from temperate and boreal wetland types with good accuracy, given hydrological and thermal soil parameters and NPP as input. Soil hydrology models have been developed to predict water table depth and soil temperature as a function of climate and soil characteristics. The result of coupling a simple calibrated CH₄ module to a land-surface scheme and a large-scale hydrology model (predicting wetland distribution interactively) within a climate model was presented. This showed a large increase in CH₄ emissions with higher temperatures. The magnitude of this change depends strongly on the CH₄-temperature
response considered (calibrated from observations). Participants agreed on the need for analogous research using more complete process-based models. Global present-day estimates of CH₄ fluxes from wetlands range between 92 and 260 Tg CH₄ per year; so there is a large uncertainty, even about the total magnitude of the flux.

Sources of Uncertainty and How to Reduce Them

Some of the most recent global wetland distribution maps were presented at the workshop, but they are still far from satisfactory despite long-standing recognition of their importance (e.g., by IGBP – INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME). Because differences are due partly to varying definitions, the necessity for a standard classification of wetlands for biogeochemical modeling purposes based on their functional properties was stressed.

In the future, remotely sensed data should make an essential contribution to mapping wetlands, but some issues remain to be resolved. Flooded forests are a major wetland type, but inundation under vegetation cover is hard to detect. Remotely sensed measurements distinguishing the seasonal and interannual variability of wetland extent, using an international standard classification, should be generated.

The relationship between temperature and CH₄ emission has frequently been described empirically by a Q₁₀ index. (Q₁₀ is the increase in the rate of a process for a 10degree [Author: degree symbol will be inserted] increase in temperature.) However, net CH₄ emission results from a combination of processes that is not usefully characterized by a single Q₁₀. High reported Q₁₀ indices for CH₄ emission may reflect the fact that temporal variation in CH₄ emission is the net effect of several processes that all depend on temperature (or in the case of NPP, temperature and light availability, which are seasonally correlated). The workshop emphasized that the different processes need to be distinguished, with their separate temperature dependencies, based on experimental evidence. The lack of data from the tropics also makes it difficult to extend temperature/CH₄ production relationships to low latitudes.

A practical modeling approach to representing the biophysics and biogeochemistry of wetlands was demonstrated, based on a tiling scheme in which wetlands are assigned a nongeoreferenced fractional cover within each cell of a dynamic global vegetation model (DGVM) embedded in a general circulation model (GCM). A next step for longer-term analysis requires the improvement of prognostic modeling of wetland areas, which depends on modeling sub-grid-scale horizontal transports of water. The water table is the on/off switch for CH₄ production; additional components include the distinction between bogs and fens (a prime determinant of CH₄ emissions) and the fractional cover of different types of vascular plants and mosses.

DGVMs predict NPP and associated biogeochemical processes based on climate, atmospheric CO₂ concentration, soil properties, and definitions of plant functional types (PFTs). But no model explicitly represents PFTs characteristic of wetlands. Carbon 14 labeling experiments were presented showing considerable differences among wetland types in CH₄ metabolism, so recognition of wetland PFTs is important for modeling CH₄ fluxes.
**Toward an Understanding of Glacial-Interglacial Cycles of CH₄**

At least three groups have tried to model changes in atmospheric CH₄ concentration between glacial and interglacial periods by linking a vegetation module to modules describing CH₄ emissions from wetlands and emissions of CH₄ and other reactive trace gases under palaeoclimate (last glacial maximum and preindustrial) boundary conditions.

There is a growing consensus that changes in wetland extent and CH₄ emission occurred but are insufficient to account for the full magnitude of change in CH₄ concentration over glacial-interglacial cycles. Wetlands persisted through glacial times in unglaciated high latitudes and were found worldwide on the exposed continental shelves. But there was no consensus among participants about which additional mechanism or mechanisms kept CH₄ concentrations low during glacial times. It was suggested that further progress will require (1) continuing development of coupled Earth system models in which climate, vegetation, emissions, and reactive chemistry are simulated together, (2) quality-controlled synthesis of the data describing wetland occurrence and dryland fire regimes (important for the oxidation capacity of the atmosphere), (3) more complete utilization of ice-core records of relevant end products of biogeochemical processes such as HCHO and NH₃, and (4) an ice-core record of the isotopes (especially 13C) of CH₄, which would distinguish (light) carbon produced by methanogenesis from other CH₄ sources.

The workshop concluded that although there are many areas of uncertainty, there is a broad consensus about what needs to be done to arrive at an improved understanding of the methane cycle. Progress can be made by creating an environment that brings together the communities involved in gathering observations, in process studies, and in modeling. Perhaps the most important gaps are the incompleteness of knowledge about the biogeochemistry of tropical wetlands and the lack of reliable information on the global distribution of wetlands.

Finally, although the workshop focused on the role of wetlands (and there is still much work to do in this area), participants urged against treating elements of the CH₄ cycle in isolation, because of the potential involvement of marine CH₄ sources, other terrestrial sources including termites, ruminants, and smouldering fires, changes in the sources and sinks of other reactive trace gases, and climate change in determining the abundance of CH₄ in the atmosphere.

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