# MATHEMATICAL MODELS OF GENERATION, UPTAKE AND EMISSION OF METHANE BY THE SOIL

*A. V. Smagin[1], M. V. Glagolev[2]*

[1] **Moscow State University, Faculty of Soil Science, Moscow**
[2] **Moscow Palace of Youth Creativity, Moscow**
**E-mail: GLAGOLEV@inmi.host.ru**

Methane is an important greenhouse gas in the climatic system and strongly influences the photochemistry of the atmosphere and global radiation balance. An important source of methane is anaerobic decomposition of organic matter in wetlands. About 60% of the emission comes from peat-rich bogs located between 50 and 70°N [Matthews and Fung, 1987]. Reducing the uncertainties in estimates of current $CH_4$ emission and predicting its future change require a process-based model to simulate $CH_4$ emissions from various environments [*Cao et al.*, 1995]. All models are selected in 3 groups:

- Process-based models
- (PBM);
- Empirical regression models
- (ERM);
- Models of mixed type
- (MMT), which include ERM-described processes and PBM-described processes.

Critical review covers on the basis of our data and literature data the following models (Tables 1-3).

The ERMs give a good result when values of input variables are close to values at which model coefficients were determined. Unfortunately we need to deviate from these values in the tasks of emission forecasting, but in this case the divergence between model calculation and future experiment will be, as rule, very big. The PBMs are too difficult for using and their coefficients must be definite for each ecosystem with a lot of expensive experiments. Thus, these models cannot be recommended to predict the emission in global scale. The MMTs

Table 3 give wrong results when they were applied (for forecasting) to some ecosystems after parameter identification for other ecosystems. But these results are not so absurd as the results which were obtained in this case from ERMs.

***Table 1.*** *Process-based models.*

| *Model (reference)* | *Object of modeling* |
|---|---|
| *Alperin et al.*, 1988 | $^{13}CH_4/^{12}CH_4$ fractionation in soil profile |
| *Andersen*, 1996 | $^{13}CH_4/^{12}CH_4$ in systems with multiple sources and sinks |
| *Andrews*, 1978 | Anaerobic digestion process |
| *Arah & Stephen*, 1998 | Methane emission from peatland |
| *Born et al.*, 1990 | Methane consumption in aerated soils of the temperate zone |
| *Buffiere et al.*, 1995 | Methanogenic biofilms |
| *Chanton et al.*, 1997 | Isotope fractionation by transport and methane-oxidation |
| *Czepiel et al.*,1994 | $CH_4$ concentration effect on $CH_4$ oxidation in temperate zone soils |
| Dörr *et al.*, 1993 | Soil texture parameterization of the $CH_4$ uptake in aerated soils |
| *Dunfield et al.*, 1993 | $CH_4$ concentration effect on $CH_4$ oxidation in peat soils |
| *El-Fadel et al.*, 1996 | Generation and transport of gas and heat in landfills |
| *Grant*, 1998 | Methanogenesis |
| *James*, 1993 | Methane flux from the Florida Everglades |
| *Hulzen et al.*, 1999 | Temperature effects on soil methane production |
| *Hütsch et al.*, 1993 | Methane oxidation in soil of the broadbalk wheat experiment |
| *Kirchgessner et al.*, 1993 | Methane emissions from a point source |
| *Levin et al.*, 1993 | Stable isotopic and concentration profiles of $CH_4$ in soil |
| Moraes & Khalil, 1993 | Permafrost methane content |
| *Peer et al.*, 1993 | Global methane emissions from landfills |
| *Romanowicz et al.*,1995 | Dissolved $CH_4$ stationary profile in the Lake Agassiz Peatlands |
| *Striegl*, 1993 | Diffusional limits to the consumption of atmospheric $CH_4$by soils |
| *Vasiliev et al.*, 1994 | Anaerobic digestion of organic matter by a microbial consortium |
| *Walter et al.*, 1996 | Methane profiles and emissions from natural wetlands |
| *Westermann et al.*, 1989 | Temperature effect on methane generation from $H_2$, $CH_3COOH$ |

**Table 2.** *Empirical regression models.*

| *Model (reference)* | *Object of modeling* |
|---|---|
| *Barber et al.*, 1988 | Gas exchange across the liquid boundary layer |
| *Born et al.*, 1990 | Methane consumption in aerated soils |
| *Bridgham & Richardson*,1992 | Temperature effect on methane flux in southern peatlands |
| *Bubier*, 1995 | Methane emission in northern peatlands |
| *Bubier et al.*, 1993a,b; 1995a,b | Methane flux in boreal peatlands, northern Canada |
| *Crill et al.*,1994 | Temperature effect on methane oxidation in a peatland |
| *Dise et al.*, 1993 | Methane Emissions from Peatlands in Northern Minnesota |
| *Dunfield et al.*, 1995 | Effect of moisture content on $CH_4$ fluxes in a humisol |
| *Gerard & Chanton.*, 1993 | Effect of live root density ($g/cm^3$) on $CH_4$ uptake rate |
| *Granberg et al.*, 1997 | Methane emission from mires in northern Sweden |
| *Hargreaves & Fowler*, 1998 | Effects of water table and soil temperature on the emission |
| *Keller & Reiners*, 1994 | Effect of diffusivity on the emission in the Atlantic lowlands |
| *King*, 1994 | Methane oxidation connected with *Calamogrostis canadensis* |
| *Klinger et al.*, 1994 | Temperature effect on $CH_4$ flux in the Hudson Bay lowland |
| *Lansdown et al.*, 1992 | Temperature effect on methane flux in a peatland |
| Liblik *et al.*, 1997 | WTL effect methane emissions (Fort Simpson, Canada) |
| *MacDonald et al.*, 1998 | Temperature and water table effects on methane emission |
| *Melloh & Crill*, 1996 | Ice thickness effect on the methane concentration |
| *Moore & Dalva*, 1993 | The influence of water table position on methane emission |
| *Moore et al.*, 1994 | Effects of water table and soil temperature on the emission |
| *Moore & Knowles*, 1990 | Temperature effect on methane flux in Quebec peatlands |
| *Moosavi et al.*, 1996 | Temperature effect on $CH_4$ flux in an Alaskan boreal wetland |
| *Nilsson & Bohlin*, 1993 | Methane concentrations in bogs and fens |
| *Roulet et al.*, 1992 | Effect of water table on the emission in northern fens |
| *Sass et al.*, 1990; 1991; 1994 | Effects of plant biomass, sand content and T on $CH_4$ flux |
| *Shurpali et al.*, 1993 | Methane flux in a Minnesota Peatland (northern Minnesota) |
| *Steudler et al.*, 1996 | Effect of pore water to methane flux |
| *Sundh et al.*, 1994; 1995 | Depth distribution of production and oxidation of $CH_4$ |
| *Taylor et al.*, 1991 | Dependence between $CH_4$ flux and net primary production |
| *Whalen et al.*, 1990 | Temperature effect on methane oxidation |
| *Whiting&Chanton,1992* | Relationship of $CH_4$ emission and live aboveground biomass |
| *Whiting&Chanton,1993* | Relationship of $CH_4$ emission and net ecosystem production |
| *Whiting et al.*, 1991 | Relationship of $CH_4$ emission and live biomass, NEE of $CO_2$ |

**Table 3.** *Models of mixed type.*

| *Model (reference)* | *Object of modeling* |
|---|---|
| *Cao et al.*, 1995; 1996 | Methane emissions from natural wetlands and rice paddies |
| *Christensen et al.*,1996 | Methane flux from northern wetlands and tundra |
| *Frolking & Crill*, 1994 | $CH_4$ flux from a poor fen in southeastern New Hampshire |
| *Fung et al.*, 1991 | Global methane cycle |
| *Glagolev*, 1998 | Production, oxidation and transportation processes of $CH_4$ |
| *Hein et al.*, 1997 | Global atmospheric methane cycle |
| *Koschorreck &* Conrad, 1993 | Vertical profile of oxidation of atmospheric $CH_4$ in soil |
| *Potter*, 1997 | $CH_4$ production and emission from wetland |
| *Potter et al.*, 1996 | Global soil methane consumption |
| *Sebacher et al.*, 1983 | $CH_4$ flux across the air-water interface: air velocity effects |
| *Segers*, 1998 | $CH_4$ production and consumption in wetlands |
| VanderGon&vanBreemen,1993 | Plant-mediated diffusive transport of methane from soil |

**REFERENCES**


1. Alperin M.J., Reeburg W.S., Whiticar M.J. 1988. Global Biogeochem.Cycles, 2, 279-288.
2. Andersen B.L. 1996. Global Biogeochem. Cycles, 10, 191-196.
3. Andrews J.F. 1978. In: "Mathematical Models in Water Pollution Control". - A. James (ed.). – Chichester etc.: JOHN WILEY & SONS. – p. 281-302.
4. Arah J.R.M., Stephen K.D. 1998. Atmospheric Environment, 32, 3257-3264.
5. Barber T.R., Burke Jr. R.A., Sackett W.M. 1988. Global Biogeochem.Cycles, 2, 411-425.
6. Bubier J. 1995. Journal of Ecology, 83, 403-420.
7. Bubier J., Costello A., et al. 1993a. Can. J. Bot., 71, 1056-1063.
8. Bubier J.L., Moore T.R., et al. 1995a. Global Biogeochem. Cycles, 9, 455-470.
9. Bubier J.L., Moore T.R., Juggins S. 1995b. Ecology, 76, 677-693.
10. Bubier J.L., Moore T.R., Roulet N.T. 1993b. Ecology, 74, 2240-2254.
11. Born M., Dorr H., Levin I. 1990. Tellus, 42B, 2-8.
12. Bridgham S.D., Richardson C.J. 1992. Soil Biol. Biochem., 24, 1089-1099.
13. Buffiere P., Steyer J.-P., et al. 1995. Biotechnology and Bioengineering, 48, 725-736.
14. Cao M., Dent J.B., Heal O.W. 1995. Global Biogeochem. Cycles, 9, 183-195.
15. Cao M., Marshall S., Gregson K. 1996. J. Geophys. Res., 101, 14399-14414.
16. Chanton J.P., Whiting G.J., et al. 1997. Global Biogeochem. Cycles, 11, 15-27.
17. Christensen T.R., Prentice I.C., et al. 1996. Tellus, 48B, 652-651.
18. Crill P.M., Martikainen P.J., et al. 1994. Soil Biol. Biochem., 26, 1331-1339.
19. Czepiel P.M., Crill P.M., Harriss R.C. 1995. J. Geophys. Res., 100, 9359-9364.
20. Dise N.B., Gorham E., Verry E.S. 1993. J. Geophys. Res., 98, 10583-10594.
21. Dörr H., Katruff L., Levin I. 1993. Chemosphere, 26, 697-713.
22. Dunfield P., Knowles R., et al. 1993. Soil Biol. Biochem. 25, 321-326.
23. Dunfield P., Topp E., et al. 1995. Biogeochemistry, 29, 199-222.
24. El-Fadel M., Findikakis A.N., Leckie J.O. 1996. Waste Management and Res., 14, 483-504.
25. Frolking S., Crill P. 1994. Global Biogeochem. Cycles, 8, 385-397.
26. Fung I., John J., et al. 1991. J. Geophys. Res., 96, 13033-13065.
27. Gerard G., Chanton J. 1993. Biogeochemistry, 23, 79-97.
28. Glagolev M.V. 1998. In: «Global Environment Research Fund: Eco-Frontier Fellowship (EFF) in 1997». - Tokyo: Environment Agency. Global Environment Department. Research & Information Office. p. 79-111.
29. Granberg G., Mikkela C., et al. 1997. Global Biogeochem. Cycles, 11, 135-150.
30. Grant R.F. 1998. Soil Biol. Biochem., 30, 883-896.
31. Hargreaves K.J., Fowler D. 1998. Atmospheric Environment, 32, 3275-3282.
32. Hein R., Crutzen P.J. , Heimann M. 1997. Global Biogeochem. Cycles, 11, 43-76.
33. Hulzen J.B., Segers R., et al. 1999. Soil Biol. Biochem., 31, 1919-1929.
34. Hütsch B.W., Webster C.P., Powlson D.S. 1993. Soil Biol. Biochem., 25, 1307-1315.
35. James R.T. 1993. Ecological Modelling, 68, 119-146.
36. Keller M., Reiners W. 1994. Global Biogeochem. Cycles, 8, 399-405.
37. King G.M. 1994. Appl. Environ. Microbiol., 60, 3230-3227.
38. Kirchgessner D.A., Piccot S.D., Chadha A. 1993. Chemosphere, 26, 23-44.
39. Klinger L.F., Zimmerman P.R., et al. 1994. J. Geophys. Res., 99, 1469-1494.
40. Koschorreck M., Conrad R. 1993. Global Change Biology, 7, 109-121.
41. Lansdown J.M., Quay P.D., King S.L. 1992. Geochim. et Cosmochim. Acta, 56, 3493-3503.
42. Levin I., BergamaschiP., et al. 1993. Chemosphere, 26, 161-177.
43. Liblik L.K., Moore T.R., et al. 1997. Global Biogeochem. Cycles, 11, 485-494.
44. MacDonald J.A,, Fowler D., et al. 1998. Atmospheric Environment, 32, 3219-3227.
45. Matthews E., Fung I. 1987. Global Biogeochem. Cycles, 1, 61-86.
46. Melloh R.A., Crill P.M. 1996. Global Biogeochem. Cycles, 10, 247-254.
47. Moore T.R., Dalva M. 1993. J. Soil Scien., 44, 651-664.
48. Moore T.R., Heyes A., Roulet N.T. 1994. J. Geophys. Res., 99, 1455-1467.
49. Moore T., Knowles R. 1990. Biogeochemistry, 11, 45-61.
50. Moosavi S.C., Crill P.M., et al. 1996. Global Biogeochem. Cycles, 10, 287-296.
51. Moraes F., Khalil M.A.K. 1993. Chemosphere, 26, 595-607.
52. Nilsson M., Bohlin E. 1993. J. Ecol., 81, 615-625.
53. Peer R.L., Thorneloe S.A., Epperson D.L. 1993. Chemosphere, 26, 387-400.
54. Potter C.S. 1997. Global Biogeochem. Cycles, 11, 495-506.
55. Potter C.S., Davidson E.A., Verchot L.V. 1996. Chemosphere, 32, 2219-2246.
56. Romanowicz E.A., Siegel D.I., et al. 1995. Global Biogeochem. Cycles, 9, 197-212.
57. Roulet N.T., Moore T., et al. 1992. Tellus, 44B, 100-105.
58. Sass R.L., Fisher F.M., et al. 1990. Global Biogeochem. Cycles, 4, 47-68.
59. Sass R.L., Fisher F.M., et al. 1991. Global Biogeochem. Cycles, 5, 335-350.

60. Sass R.L., Fisher F.M., et al. 1994. Global Biogeochem. Cycles, 8, 135-140.
61. Sebacher D.I., Harriss R.C., Bartlett K.B. 1983. Tellus, 35B, 103-109.
62. Segers R. 1998. Biogeochemistry, 41, 23-51.
63. Shurpali H.J., Verma S.B., Clement R.J. 1993. J. Geophys. Res., 98, 20649-20655.
64. Steudler P.A., Melillo J.M., et al. 1996. J. Geophys. Res., 101 (D13), 18547-18554.
65. Striegl R.G. 1993. Chemosphere, 26, 715-720.
66. Sundh I., Mikkelä C., et al. 1995. Soil Biol. Biochem., 27, 829-837.
67. Sundh I., Nilsson M., et al. 1994. Microbial Ecology, 27, 253-265.
68. Taylor J.A., Brasseur P.R., et al. 1991. J. Geophys. Res., 96, 3013-3044.
69. Van der Gon H.A.C.D., van Breemen N. 1993. Biogeochemistry, 21, 177-190.
70. Vasiliev V.B., Vavilin V.A., et al. 1993. Water Resources, 20, 633-643.
71. Walter B.P., Heimann M., et al. 1996. Geophys. Res. Let., 23, 3731-3734.
72. Wang Z.P., DeLaune R.D., et al. 1993a. Soil Sci. Soc. Am. J., 57, 382-385.
73. Westermann P., Ahring B.K., Mah R.A. 1989. Appl. Environ. Microbiol., 55, p. 1262-1266.
74. Whalen S.C., Reeburgh W.S., Sandbeck K.A. 1990. Appl. Environ. Microbiol., 56, p. 3405-3411.
75. Whiting G.J., Chanton J.P. 1992. Global Biogeochem. Cycles, 6, 225-231.
76. Whiting G.J., Chanton J.P. 1993. Nature, 364, 794-795.
77. Whiting G.J., Chanton J.P., et al. 1991. J. Geophys. Res., 96, 13067-13071.