Development of Emission Factors for GHGs and Associated Uncertainties

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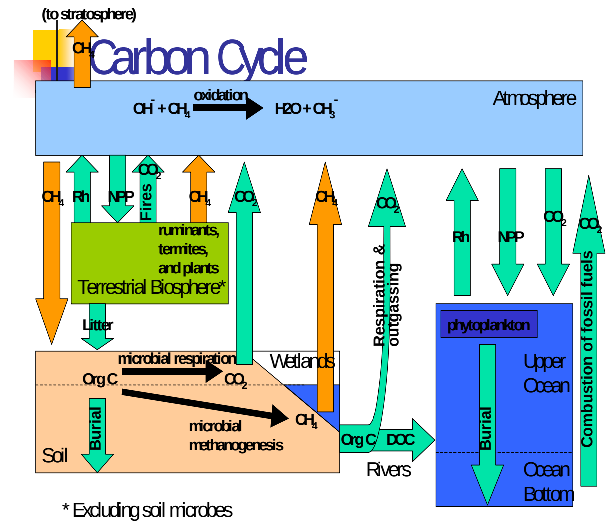
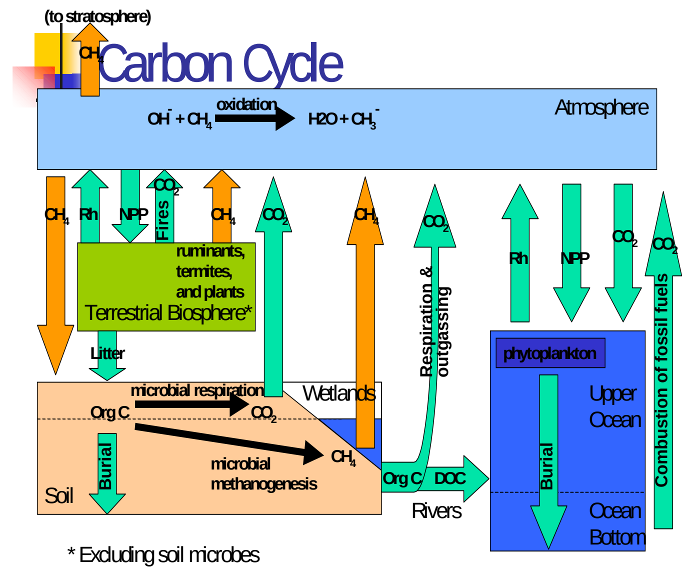
Development of Region-Specific Emission Factors : Case Study of Methane-Emissions from Wetlands

- ***Spatio-temporal***
- Interactions among ***physical***, ***chemical*** and ***biological*** factors responsible for methane emissions
- Wetlands contribute to about 25% [145 Tg CH_4 per year) of total methane emissions (***natural*** as well as ***anthropogenic***).



Wetland : Stratification

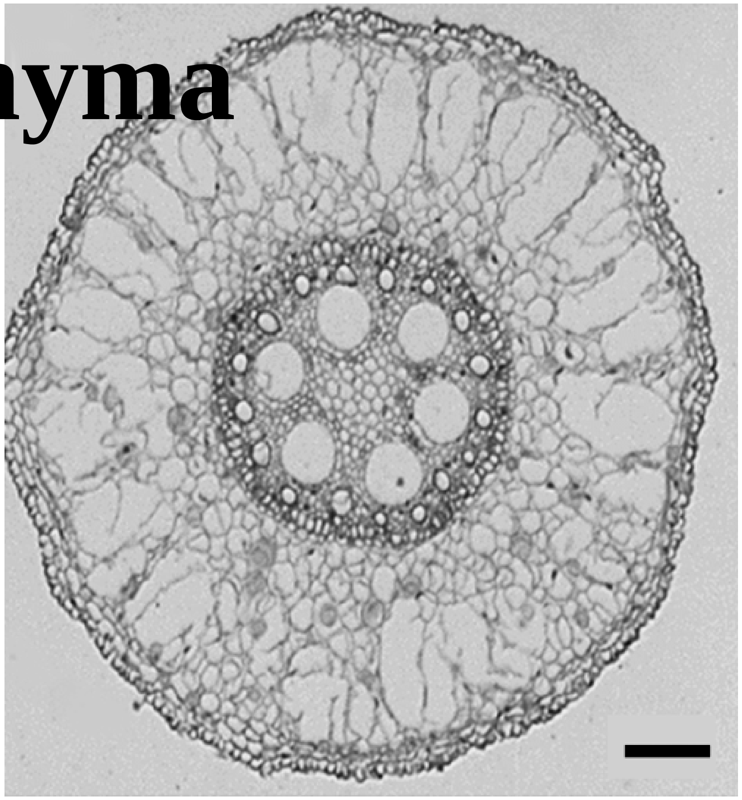
- Sub-surface (anaerobic) zone containing methanogenic bacteriaproducing methane
- Surficial (aerobic) zone containing methanotrophic bacteria which oxidizes methane



Methane Release from Wetlands to Atmosphere

- Diffusion
- Ebullition
- Transport through arenchymous vascular plants
- Daily rates of CH_4 emission in wetlands are normaly 100 mg m^{-2} day^{-1}

Aerenchyma

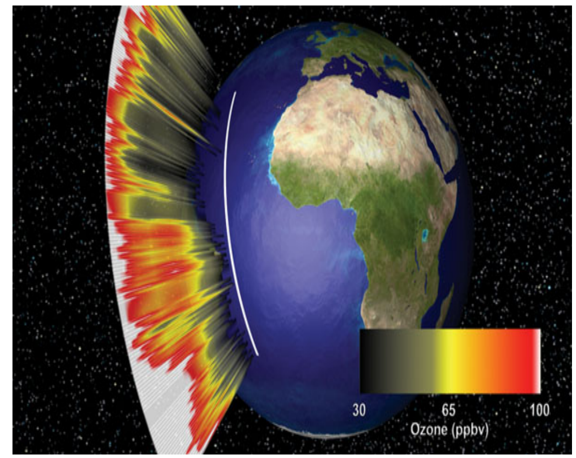


Ecosystem Controls on CH_4 Emissions from Wetlands

- Water Table Position
- Temperature
- Plant Community Compositions

Importance of Methane

- N_2, O_2 and Argon comprise 99.9% of the total dry air.
- Many trace gases including methane exist at the level of uL/L or even much less.
- However, despite their low concentrations many of these trace gases profoundly influence the oxidative photochemistry of the the troposphere and the earth's energy balance.
- ***CH$_4$ has increased by about 13 % between (1978 and 1999) [Whalen, 2005]***

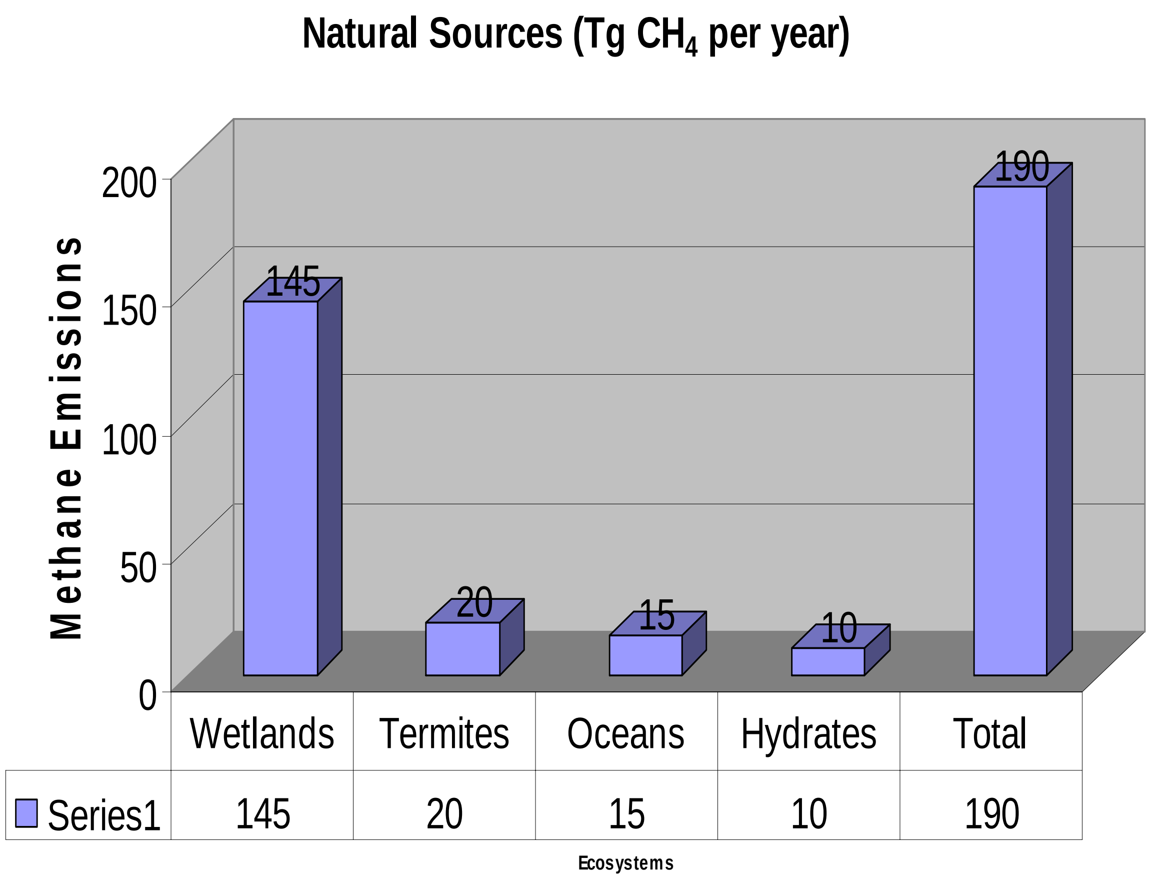


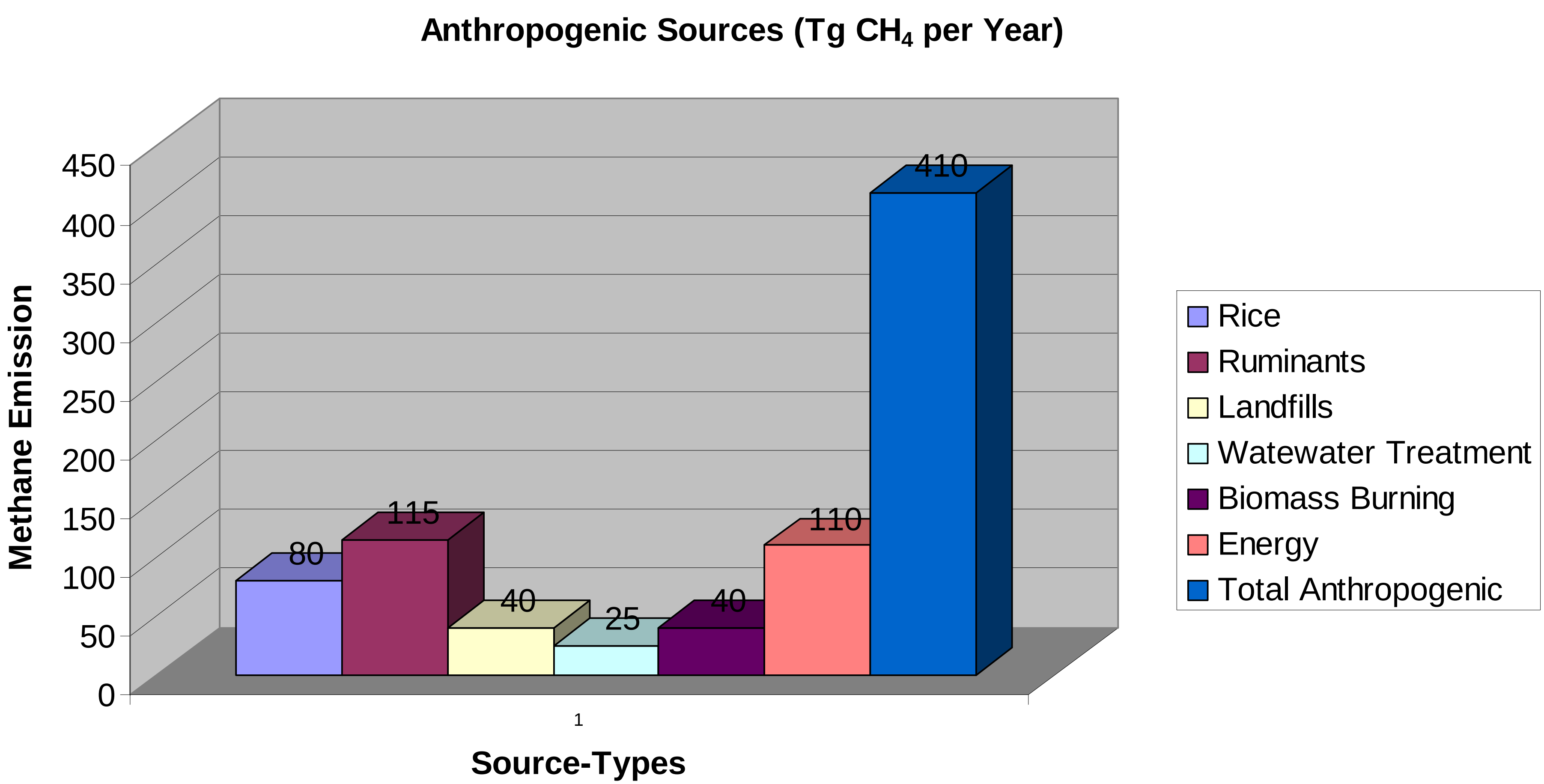
Lovelock and Margulis (1974)

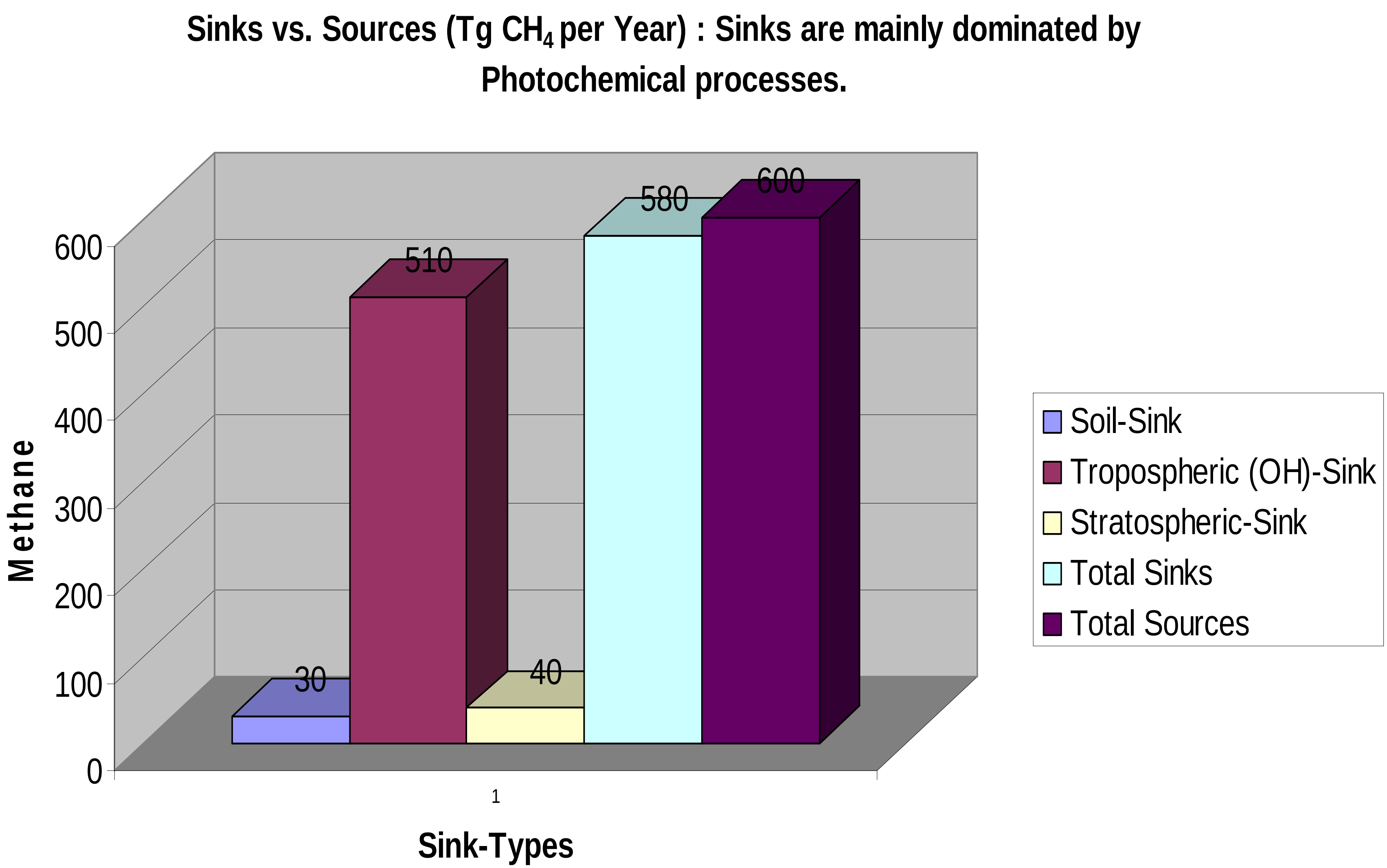
Composition of the atmosphere has historically been maintained in close homeostasis by

- Various microbial metabolic processes which are responsible for the production and consumption of trace gases
- The major sources and sinks in the atmospheric CH_4 budget have been presented in the subsequent slides.
- However, *many of these terms are poorly quantified and understood.*
- This introduces *considerable uncertainty* in the model predictions (Whalen, 2005).

Methane Sources and Sinks




Anthropogenic Sources (Tg CH4 per Year)
Methane Emission
450
400
350
300
250
200
150
100
50
0
80
115
40
25
40
110
410
1
Source-Types
Rice
Ruminants
Landfills
Watewater Treatment
Biomass Burning
Energy
Total Anthropogenic


Sinks vs. Sources (Tg CH_4 per Year) : Sinks are mainly dominated by Photochemical processes.
Methane
600
500
400
300
200
100
0
30
510
40
580
600
1
Sink-Types
Soil-Sink
Tropospheric (OH)-Sink
Stratospheric-Sink
Total Sinks
Total Sources

Methane Consumption and Emission

- Roughly 85% of the total CH_4 emitted from the earth's surface is oxidized in the troposphere by OH-radical.
- About 9% enters the stratosphere, reacts with with Cl-atoms to form HCl.
- Considering all these removal mechanisms, the present atmospheric life-time of CH_4 is about 8.4 years.

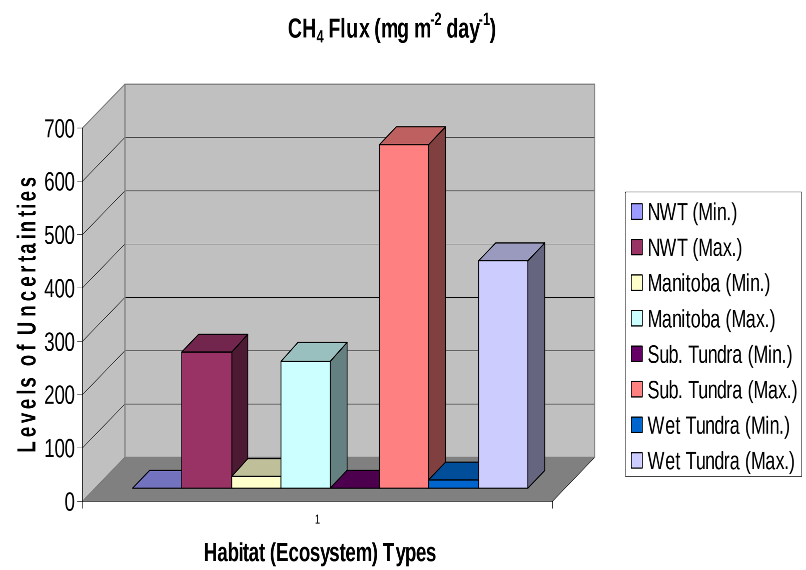
Modelling Approaches [Whalen, 2005; Bubier and Moore, 1994; Ridgewell et al. 1999; Walter and Heimann, 2000]

- The major shortcoming of climate models is the lack of comprehensive understanding of the linkage between biogeochemical processes and the troposphere.
- Thus, the present modelling thrust is on integrating site-specific and time-specific studies so as to develop process-oriented simulation models suitable for incorporation into large scale models of climate change .

Uncertainties : Arctic and Boreal (Habitats and Location Types)

Source : Liblik et al. (1997); Bellisario et al. (1999); Whalen and Reeburgh (1992); Bartlett et al. (1992)

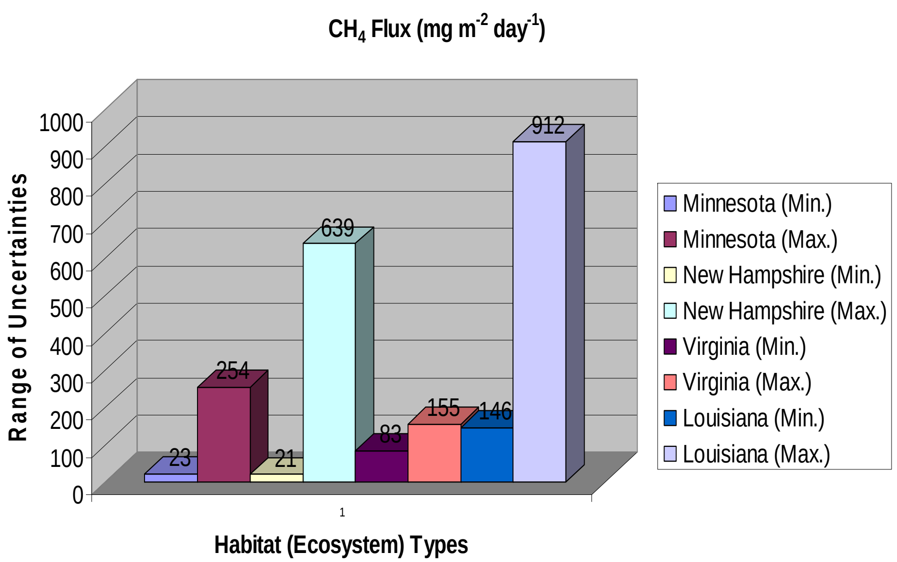
- Fens, bogs, ponds, palsas *(Northwest Territories)*
- Bogs, rich fens *(Manitoba)*
- Subarctic tundra *(Alaska)*
- Wet meadow *(Alaska)*



Uncertainties : Temperate and Sub-tropical (Habitats and Location Types)

Source : Crill et al. (1988); Frolking and Crill (1994); Wilson et al. (1989); Alford et al. (1997)

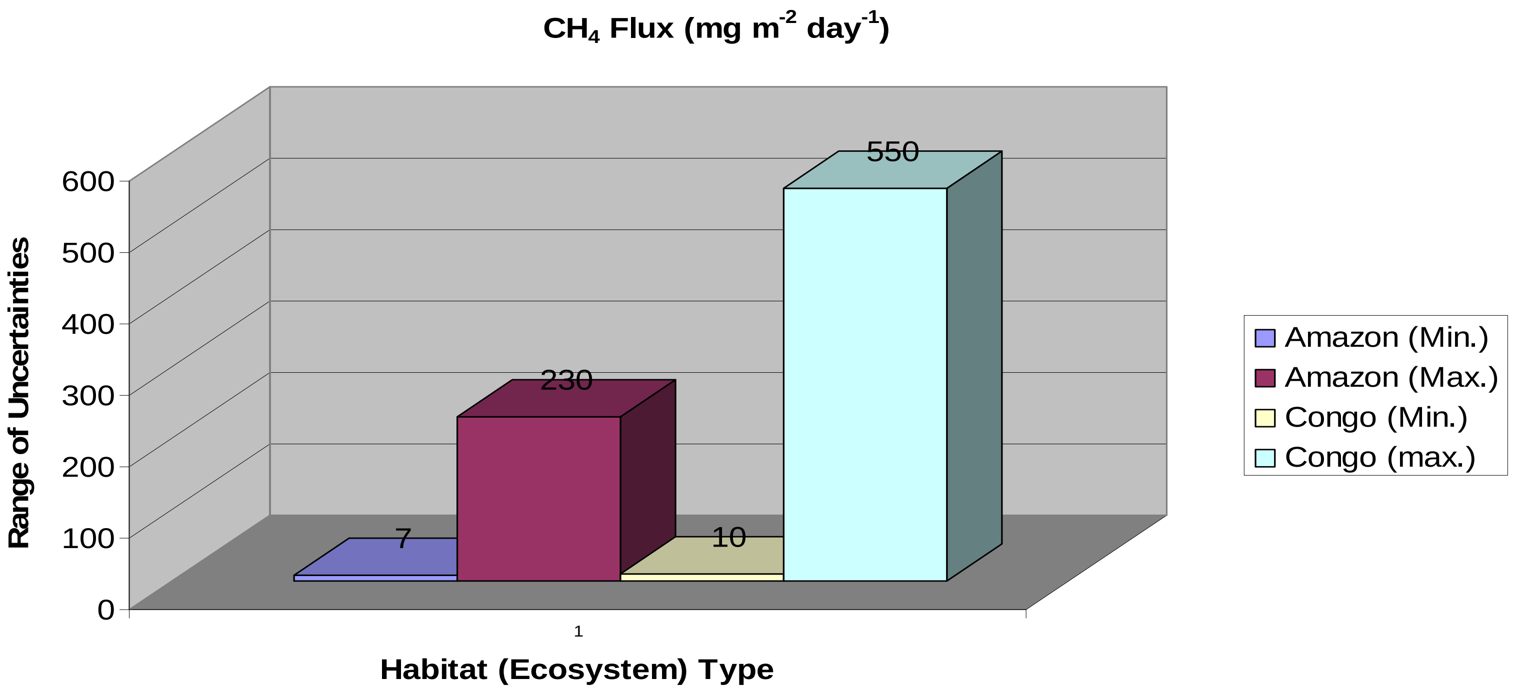
- Open and forest bog, fen *(Minnesota)*
- Poor fen *(New Hampshire)*
- Swamp *(Virginia)*
- Swamp forest, marsh *(Louisiana)*

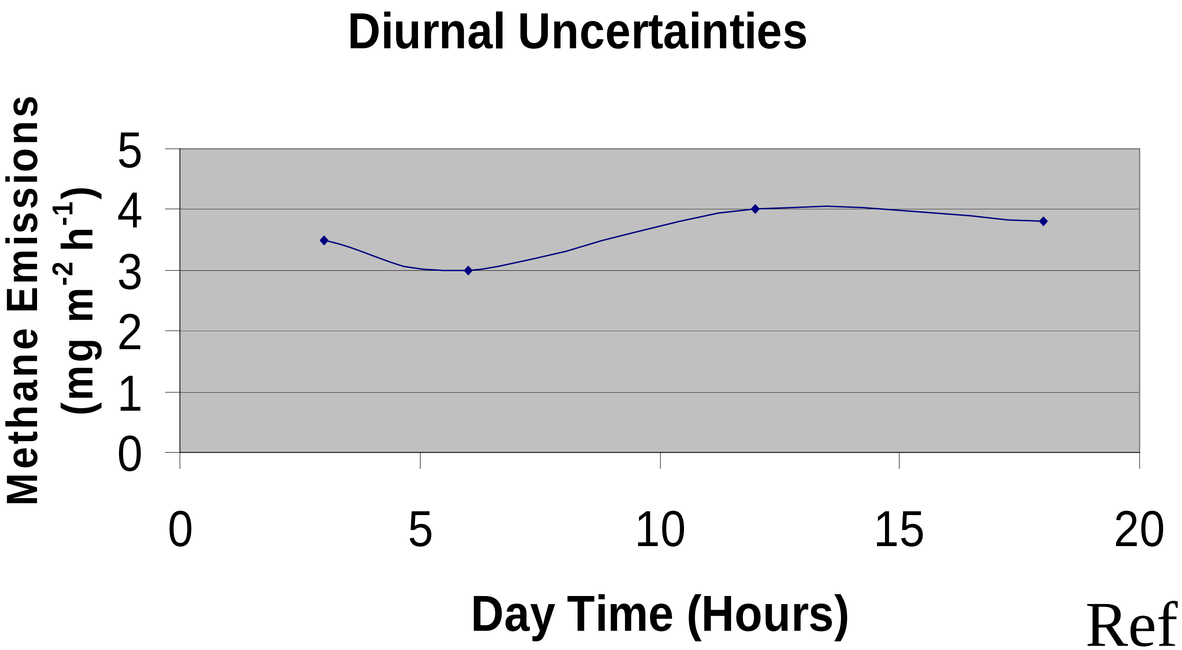


Uncertainties : Tropical (Habitats and Location Types)

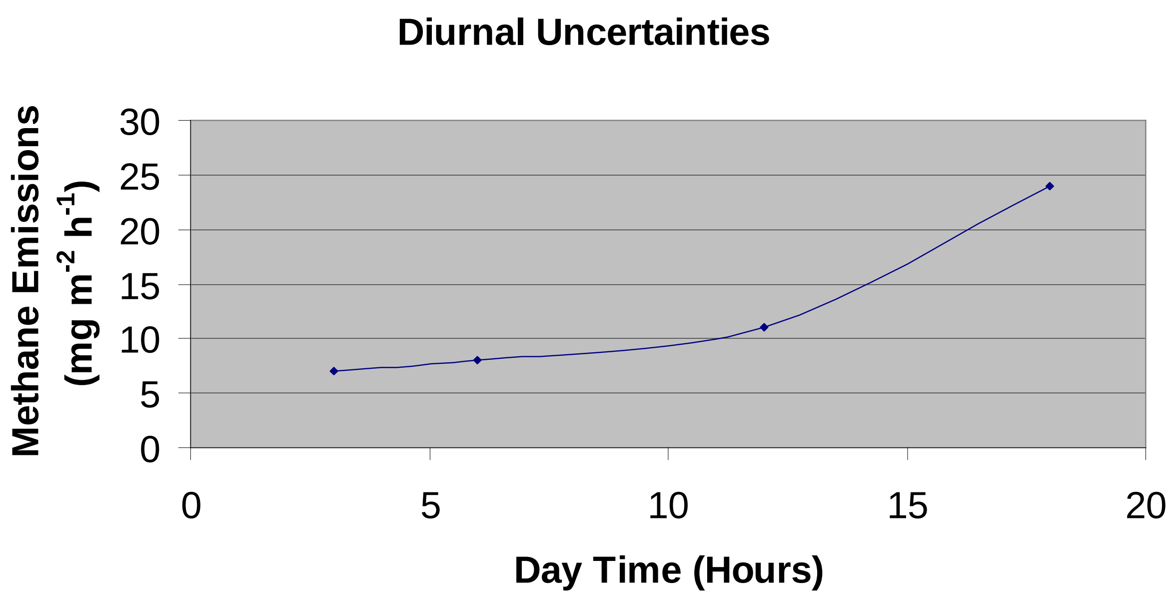
Source : Bartlett et al. (1988); Devol et al. (1990); Tathy et al. (1992)

- Flooded forests & grass mats *(Amazon Floodplain)*
- Flooded forests *(Congo River Basin)*





Ref. : Zhang et al. 2007.



There are spatial as well as seasonal variations in methane emissions. Methane emission, *inter alia*, depends on the following parameters :

- Temperature;
- Soil (sediment)-pH;
- Organic carbon;
- Redox-potential;
- Wind-speed;
- Solar-radiation;
- Physico-chemical water quality parameters; and
- Adjacent bio-spheric composition.

Some pertinent observations which have helped in developing the emission factors presented in this paper can be summarized as follows :

- For almost all the water bodies, methane emissions are highest in summer months and lowest in winter months. In rainy season, they lie somewhere in-between.
- The vegetated region of the running water (Gomti river) shows wide variations in emissions ranging from 18 mg m^{-2} h^{-1} in winter to nearly 80 mg m^{-2} h^{-1} in summer. In rainy season the value is around 32 mg m^{-2} h^{-1}.
- The range of variation, however, is quite small in case of non-vegetated zone. For instance, this range is 4.5-8 mg m^{-2} h^{-1} in case of running water and 0.5-2.5 mg m^{-2} h^{-1} in case of standing water (lake).
- In regard to non-vegetated zones, there is one more interesting observation. For both running (river) as well as standing (lake) water, methane emissions are higher in winter and lower in summer. Whereas for vegetated zone the situation is exactly opposite.

Inferences

- The seasonal variation is mainly attributable to the dependence of microbial activity (which is the main regulating factor behind methane emission) on temperature. In fact, a closer look at the data (Singh et al., 2000) clearly indicates that temperature-dependence is far more overriding (Conrad, 1989; Khalil et al., 1991) than dependence on any other parameter, viz. soil pH, organic carbon and redox potential etc. Role of pH is limited to providing the optimum range (from 6 to 8) for methanogenesis to occur (Williams and Crawford, 1984; Worakit et al. 1986). There are some variations in methane emissions due to changes in redox-potential. However, the variations do not follow any discernible or systematic trend (Singh et al. 2000).

Inferences (contd….)

- Amount and composition (kind) of organic carbon load coming to a water body also plays a significant role. However, assuming that there is a constant amount of organic carbon load continuously flowing into the water-body almost every day (quite a valid assumption for Indian cities), it (organic carbon) can not be used as a determinant for predicting variations dependent on it.
- Therefore, the main factor which will ultimately determine the rate of methanogenesis and methane–emission is going to be the sediment or soil temperature. A thorough and systematic analysis of data clearly points towards a direct link between methane emission and temperature.
- *Stomatal conductance may also control CH4 emission in some species (Morrissey et al., 1993).*

Methanogenesis

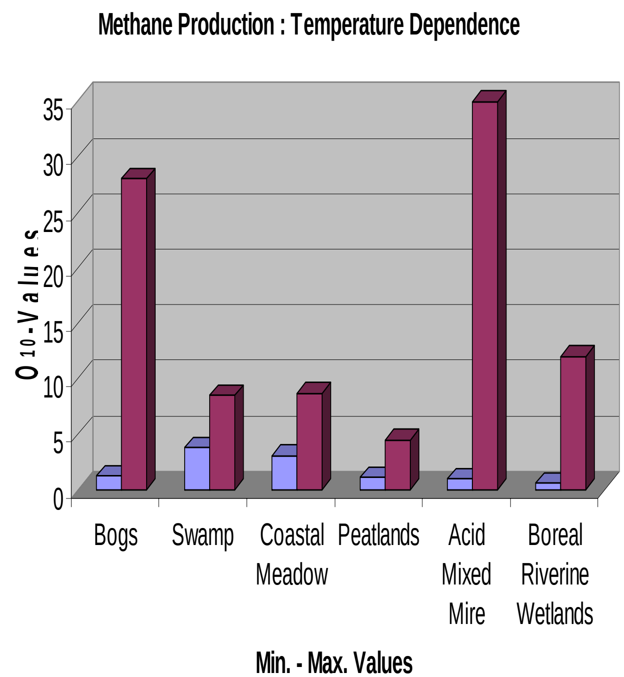
- In general, N and P inputs to water bodies, do not stimulate methanogenesis (*Williams and Crawford, 1984; Bridgham and Richardson, 1992).*
- Studies related with pH-dependence of methanogenesis give very inconsistent results *[Dunfield et al., 1993; Williams and Crawford, 1984; Richardson, 1992; Valentine et al., 1994; Bergman et al., 1998]*
- Moreover, Moore and Roulet (1995) suggested that pH, at best can be a secondary determinant for methanogenesis.

Dependence of Methanogenesis on Temperature

- Temperature exercises a strong control on methanogenesis *(Zeikus and Winfrey*, *1976; Svensson*, *1984; Williams and Crawford, 1984; Dunfield et al*., *1993; Wagner and Pfieffer*, *1997; McKenzie et al*., *1998)*

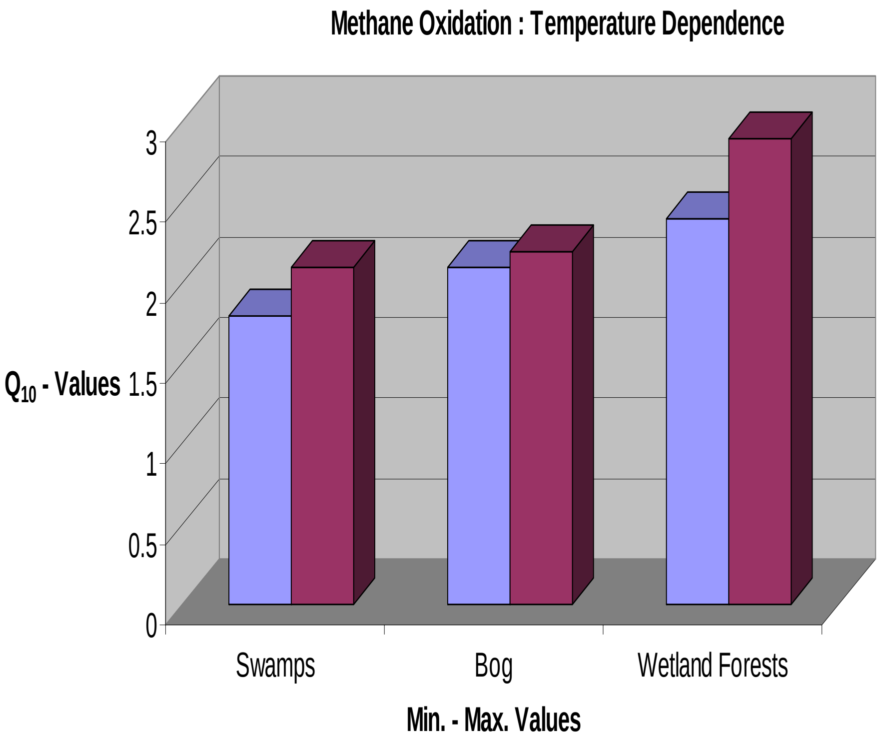
Dependence of Methane Production on Temperature : Variations in Q10-Values

- **Bogs** : *Dunfield et al. (1993); Velentine et al. (1994); Nedwell and Watson (1995); Updegraff et al. (1995); Yavitt et al. (2000); Frenzel and Karofeld (2000)*
- **Swamp** : *Westerman and Ahring (1987); Westerman (1993)*
- **Coastal Meadows** : *Prieme (1994)*
- **Peatlands :** *Yavitt et al. (1997)*
- **Acid Mixed Mire** : *Bergman et al. (1998)*
- **Boreal Riverine Wetlands** : *McKenzie et al. (1998)*



Methane Oxidation : Temperature-Dependence

- **Swamps** : *Dunfield et al. (1993)*
- **Bogs** : *Nedwell and Watson (1995); Whalen and Reeburgh (1996)*
- **Wetland Forests** : *Megonigal and Schlesinger (2002)*



Results and Discussion

The emission factors as functions of temperature for four different types of zones are presented below (equations 1 through 4) :

Running Water (River) :

Vegetated Zone

$$\text{Emission Factor} = 0.3963\,(\text{Temp})^2 - 18.021\,(\text{Temp}) + 209.83 \qquad \text{-(1)}$$

Non-Vegetated Zone

$$\text{Emission Factor} = 0.0128\,(\text{Temp})^2 - 0.8654\,(\text{Temp}) + 19.006 \qquad \text{-(2)}$$

Stagnant Water (Lake) :

Vegetated Zone

$$\text{Emission Factor} = 0.4169\,(\text{Temp})^2 - 20.860\,(\text{Temp}) + 256.29 \qquad \text{-(3)}$$

Non-Vegetated Zone

$$\text{Emission Factor} = 0.0241\,(\text{Temp})^2 - 1.266\,(\text{Temp}) + 16.545 \qquad \text{-(4)}$$

These models can be used as emission factors for the similar region and provide an important step forward in the area of developing region-specific emission factors (Figures 1 through 4).

Figure 1 : Running Water (River) : Vegetated Zone

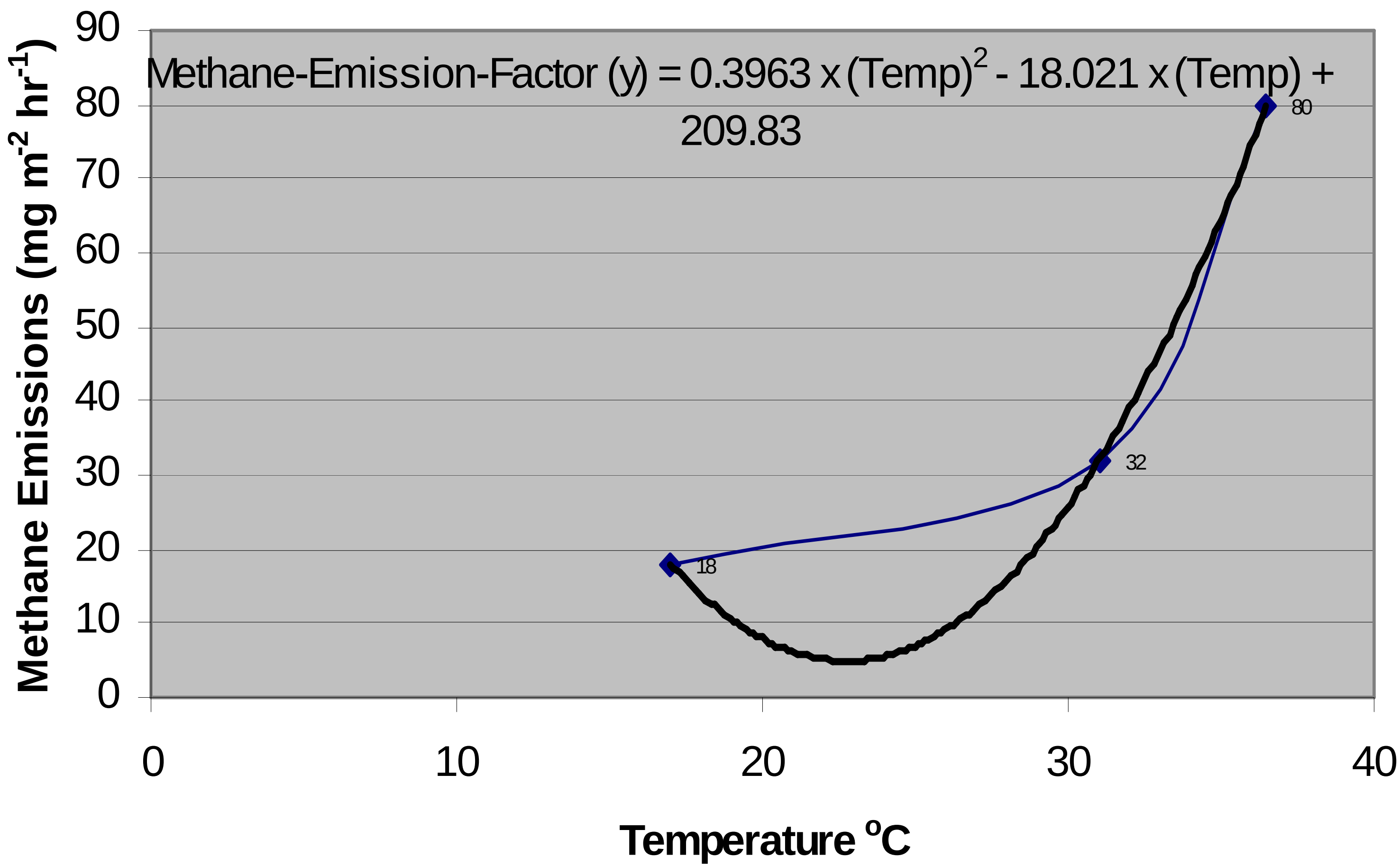


Figure 2 : Running Water : Non-Vegetated Zone

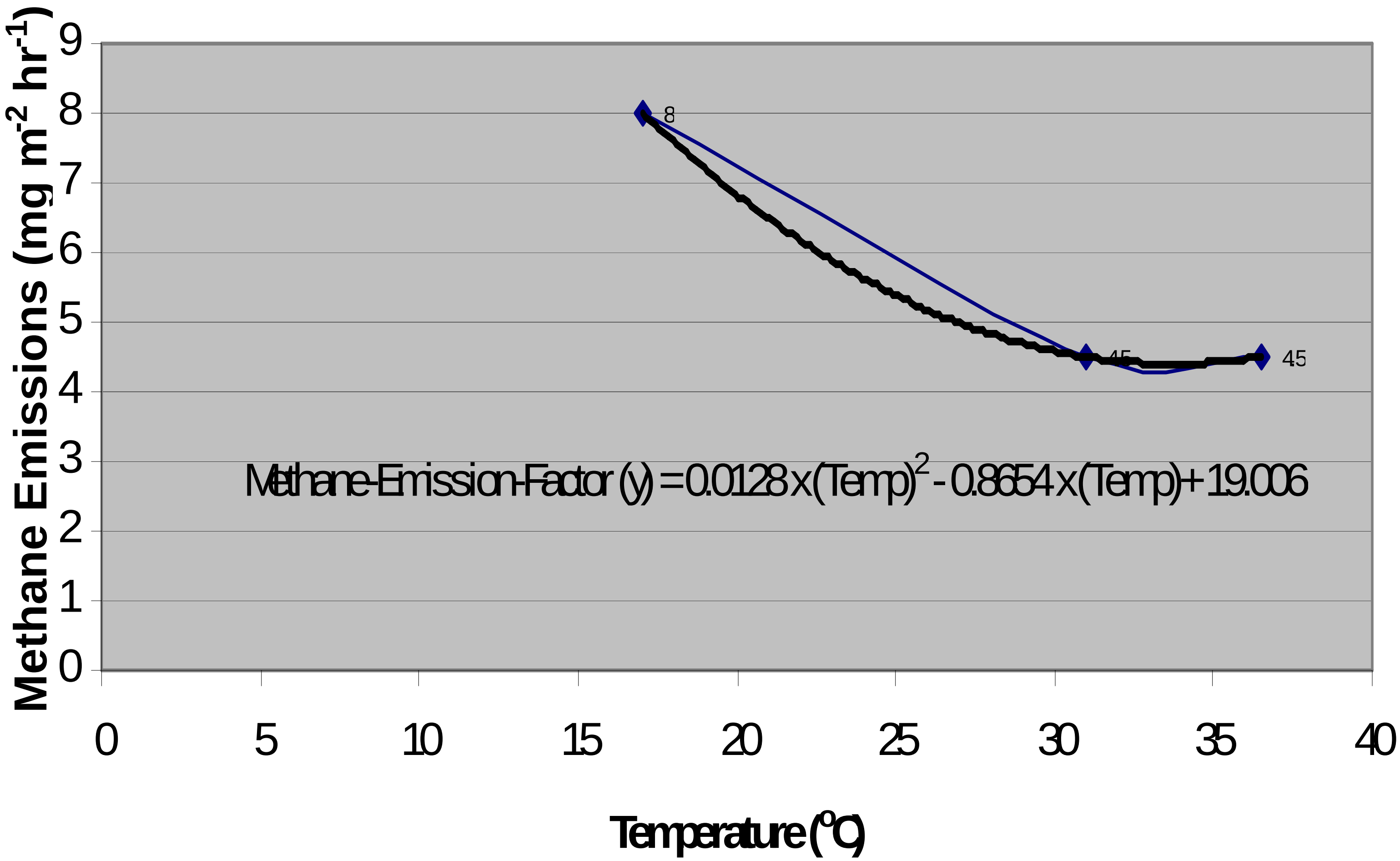
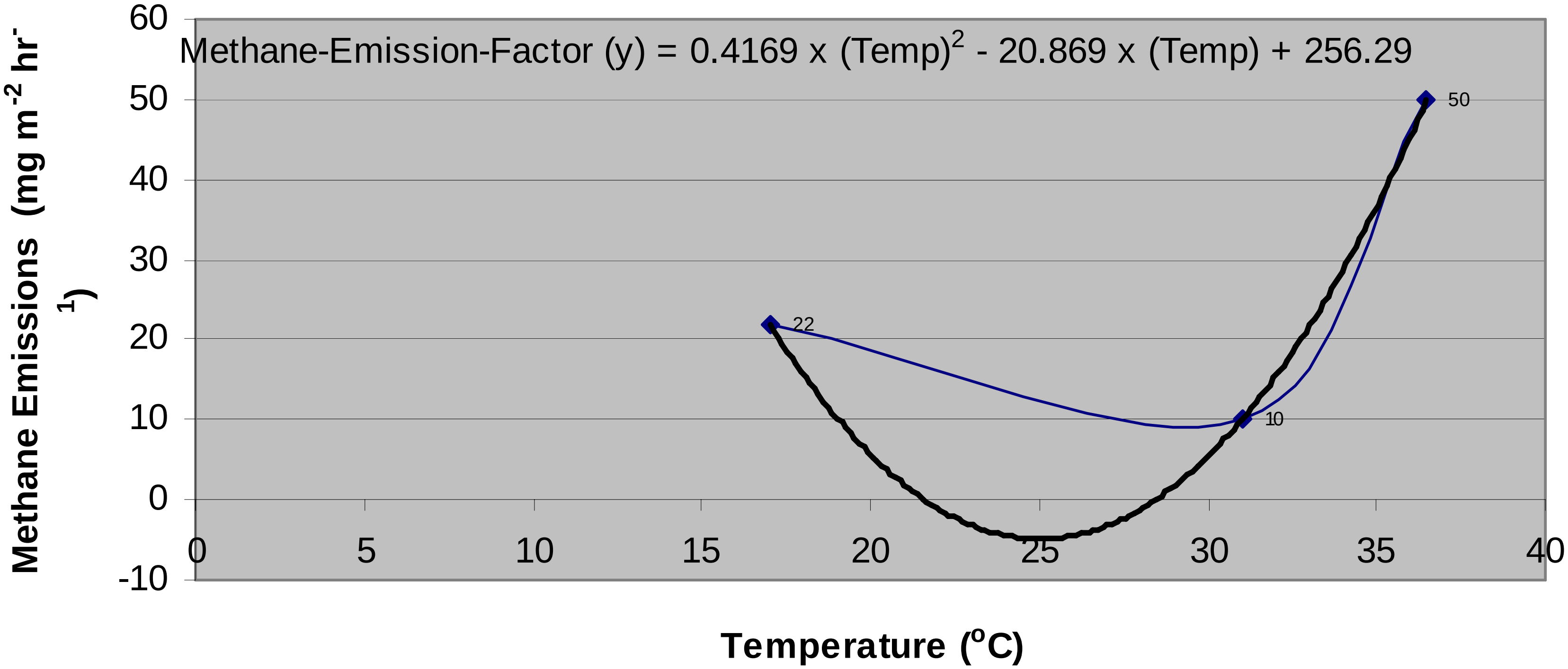
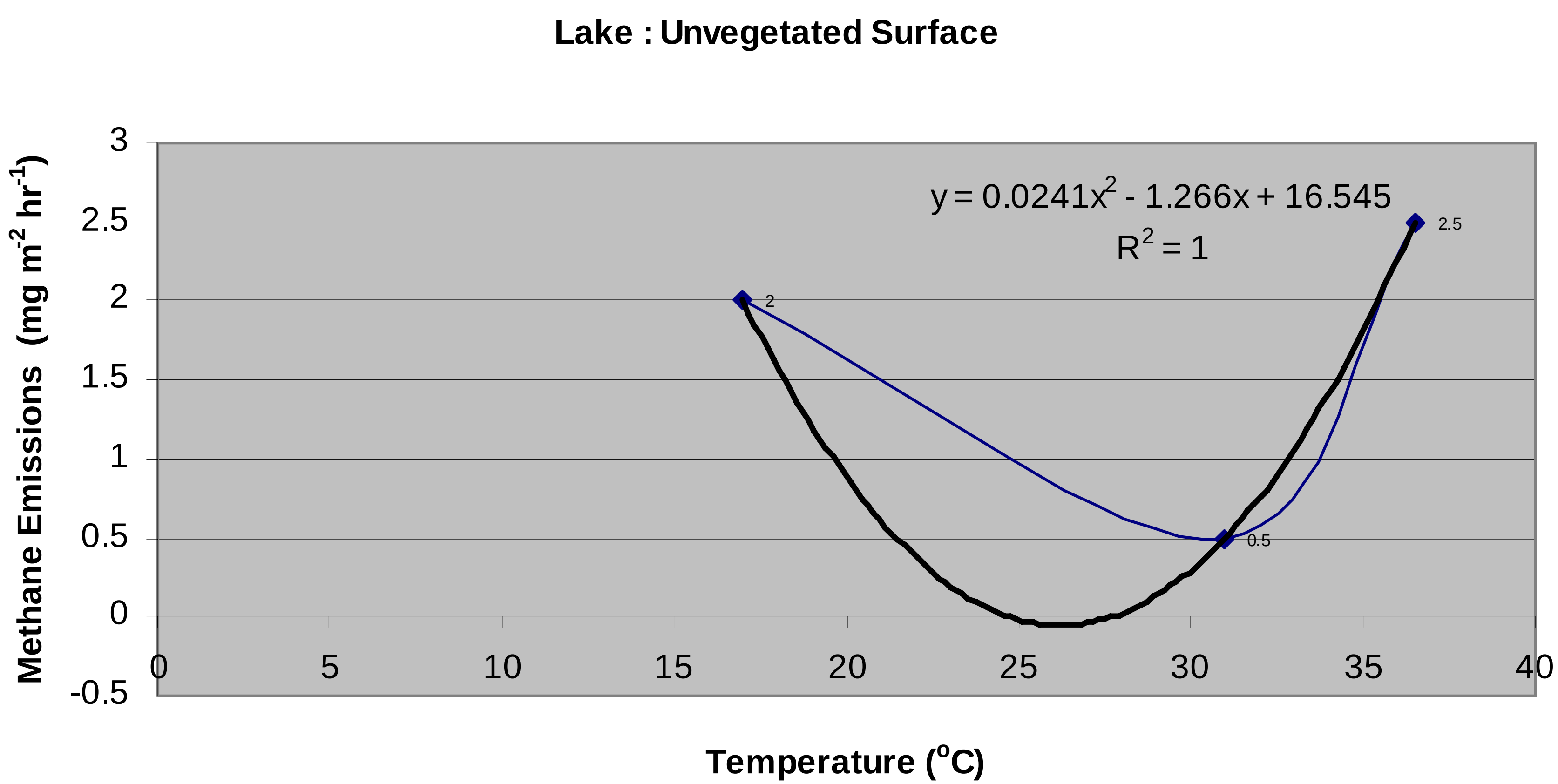


Figure 3 : Stagnant Water (Lake) : Vegetated Surface





Lake : Unvegetated Surface
y = 0.0241x2 - 1.266x + 16.545
R2 = 1
2
0.5
2.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
5
10
15
20
25
30
35
40
Methane Emissions (mg m-2 hr-1)
Temperature (oC)

Recommendations

- A word of caution : Certain factors can suddenly transform a GHG-source into a GHG-Sink and vice-versa. *For instance , a seasonal reduction in the water table position transformed atemperate swamp from an atmospheric* CH_4*-source to a* CH_4*-sink (Harris et al., 1982).*
- In India, some studies have been very recently initiated by dividing the whole watershed into various smaller grids depending on their ecological characteristics.
- Each of these grids would be monitored and studied under the following subcategories: (a) open water; (b) flooded forest; and (c) aquatic macrophyte zone.
- These emissions would then be summed up for every grid and then appropriately integrated over all the grids so as to estimate the emission for the whole watershed area.

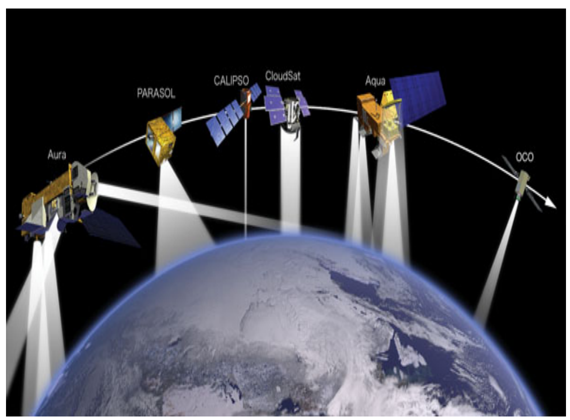
Recommendations (contd..)

- Since the main scientific debate at the moment is centered around the uncertainties associated with extrapolating emissions measured at selected parts at selected intervals of time, monitoring would have to be extended over widely different ecological zones and over longer time frames in order to obtain region-specific spatio-temporal emission-factors (functions).
- This will not only reduce the spatial uncertainties but also the uncertainties associated with diurnal, seasonal and annual variations.
- There is a growing consensus amongst scientists world-over that these emissions should be estimated both before and after construction of each dam so as to understand, analyze and quantify the net global warming/GHG-emission potential of various hydroelectric dams.
- The focus of these field studies should be on developing region-specific emission factors in accordance with recent IPCC guidelines.

Thank  You

The "A-Train". The figure on the left illustrates the constellation of satellites known as the "A Train," which will make nearly contiguous observations of many facets of the

Earth system. Courtesy : NASA.



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