

Introduction

Biologic methanogenesis in wetlands has been estimated to account for 25% of the total natural and anthropomorphic emissions of methane. (Whalen et al., 2003) Representation of this process is therefore vital to understanding methane in the atmosphere, about which, many mysteries remain. Methane is a potent greenhouse gas, and there is potential for feedback between global warming and methanogenesis. The photo-dissociation of methane in the stratosphere is thought to be an important control of water vapor concentrations there, a process which may also influence climactic change. Even the simple trend in global methane concentrations raises questions, for instance, why has its rate of increase declined?

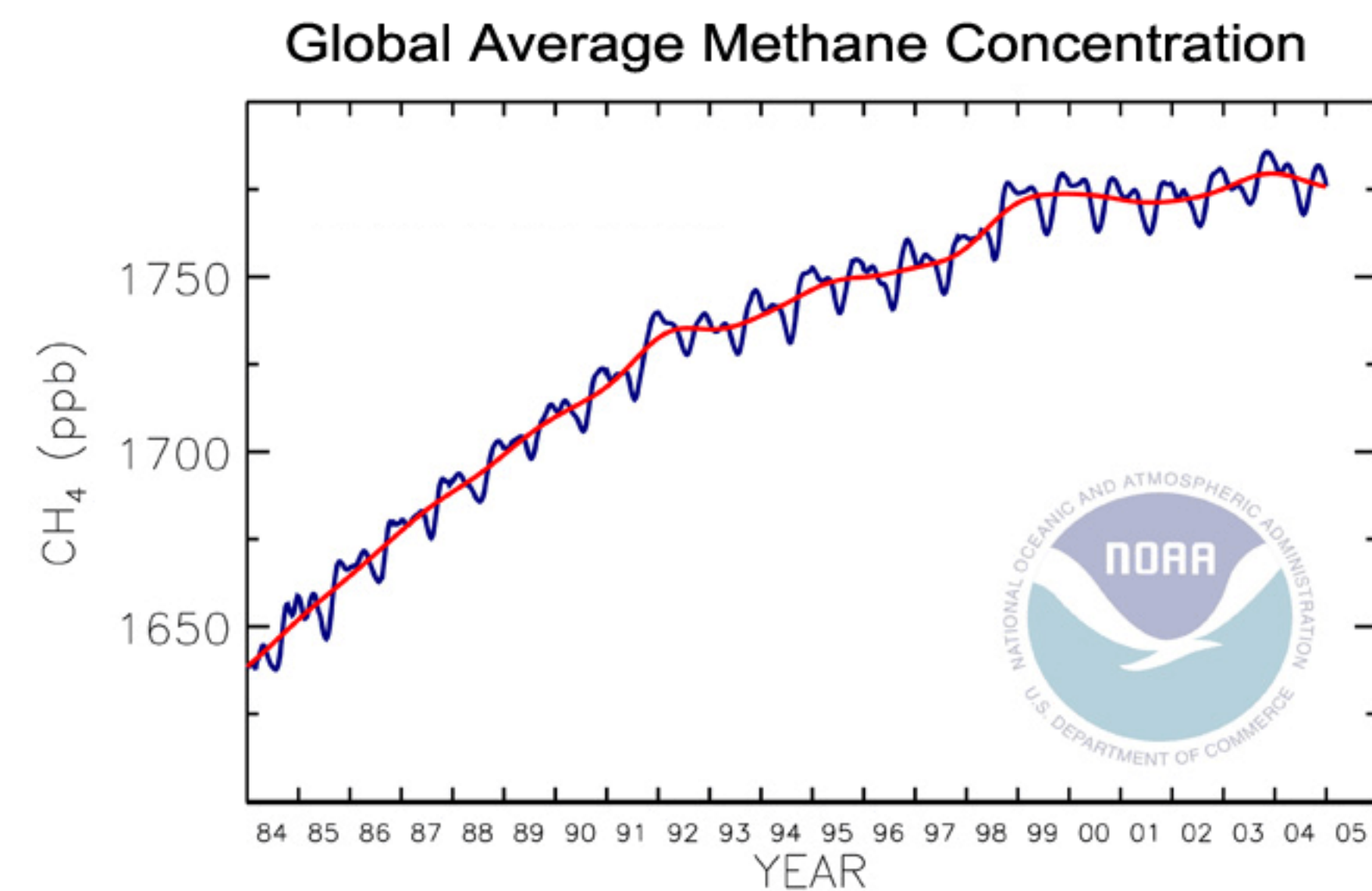


Figure 1. Global average methane concentrations from 1984 to 2005.

Methods

The objective of this work is to produce a model of methanogenesis which may effectively form a part of a land surface model within a global climate model (GCM). To that end, the model must be capable of representing processes on a large spatial scale and must rely on information obtained on such scales.

Wetlands may form a greater or lesser proportion of the area represented by a GCM grid-cell, and that proportion may vary over time. Concepts from TOPMODEL were utilized to represent this spatial and temporal variability as they were amenable to the representation of hydrology on GCM scales. (Bevin & Kirkby, 1979, Curie et al., 2007)

Making assumptions about soil transmissivity and the water table gradient, TOPMODEL utilizes a value known as the topographic index, (a.k.a. the wetness index) this value be understood as a measure of the tendency of any topographic point to become saturated. Importantly, points with equal topographic indices are equally likely to be saturated; therefore one may describe the hydrology of a region by working with histograms of topographic indices rather than large topographic data sets.

Using such a histogram, and values for soil wetness from a land surface model, in this case the Simple Biosphere Model (SiB), estimates of wetland area may be produced.

With these estimates, and an Arrhenius-type equation to model the temperature dependence of respiration, wetland methane emissions may be calculated. (i.e. Bloom et al., 2010)

Methods (continued)

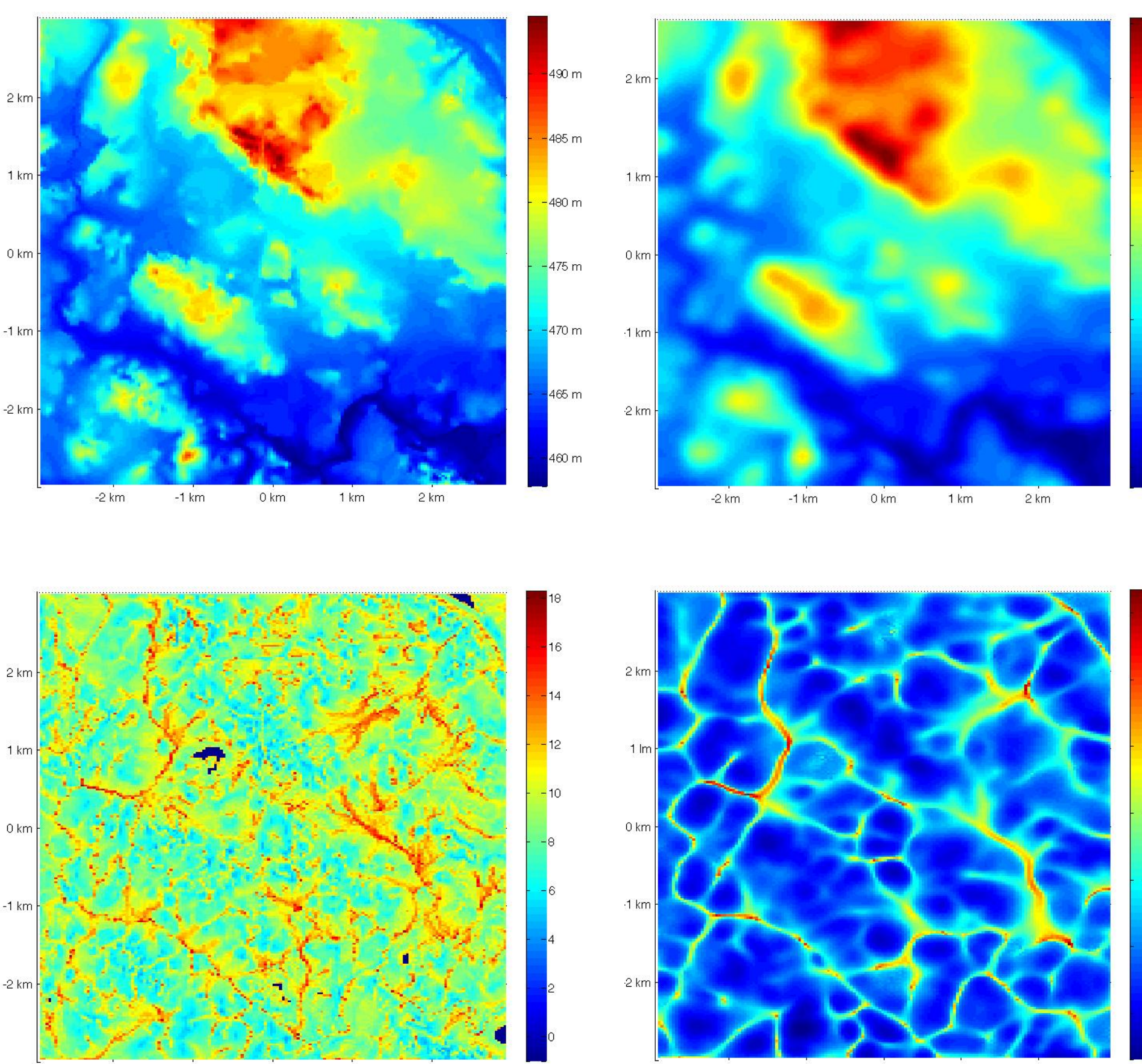


Figure 2. Elevations (above) and topographic indices (below) without smoothing (left) and with smoothing (right) in the 6 km² surrounding the WLEF site (45.9451°N, 90.2732°W). Smoothing appears unrealistic at this scale, but avoids numerical errors at larger scales.

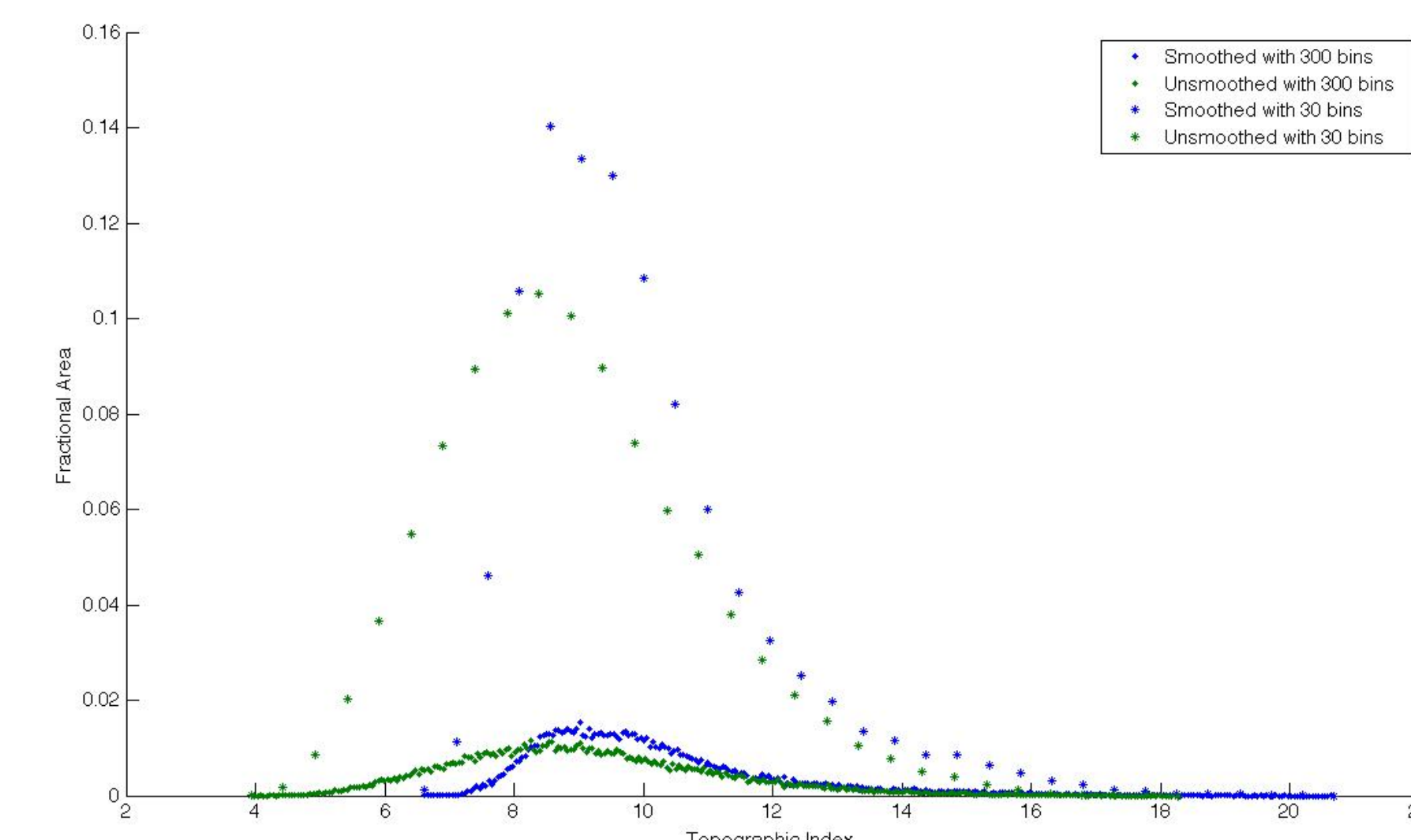


Figure 3. Histograms of the topographic index, smoothed (blue) and unsmoothed (green); with 30 bins (stars) and 300 bins (circles). When using 300 bins, the addition or subtraction of one bin in the relevant region results in a ~0.5% change in area.

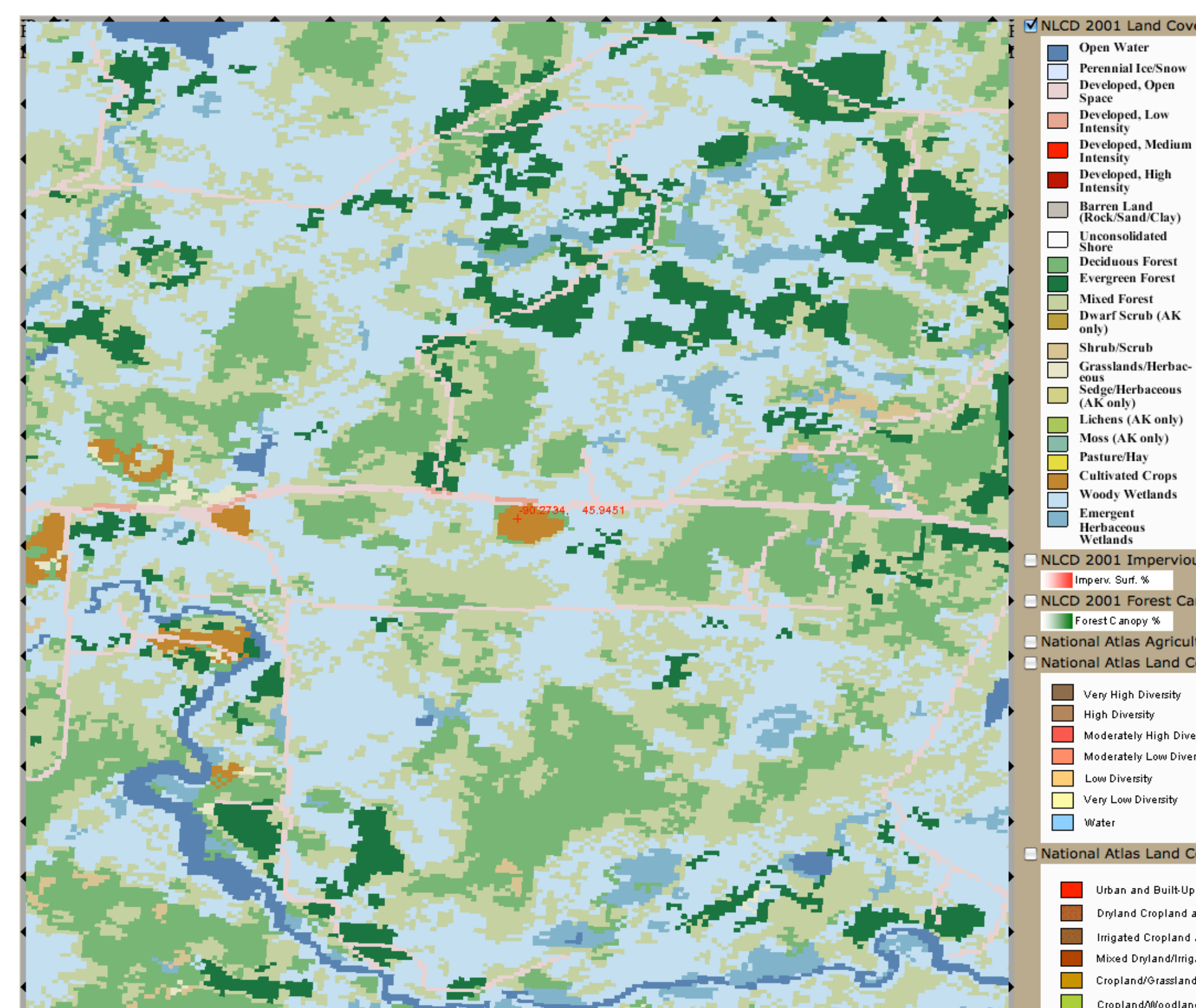


Figure 4. Classifications, from the National Atlas of Land Cover 2001 (200m resolution), of the region surrounding the WLEF site. Wetlands account for ~27% of the area.

Results

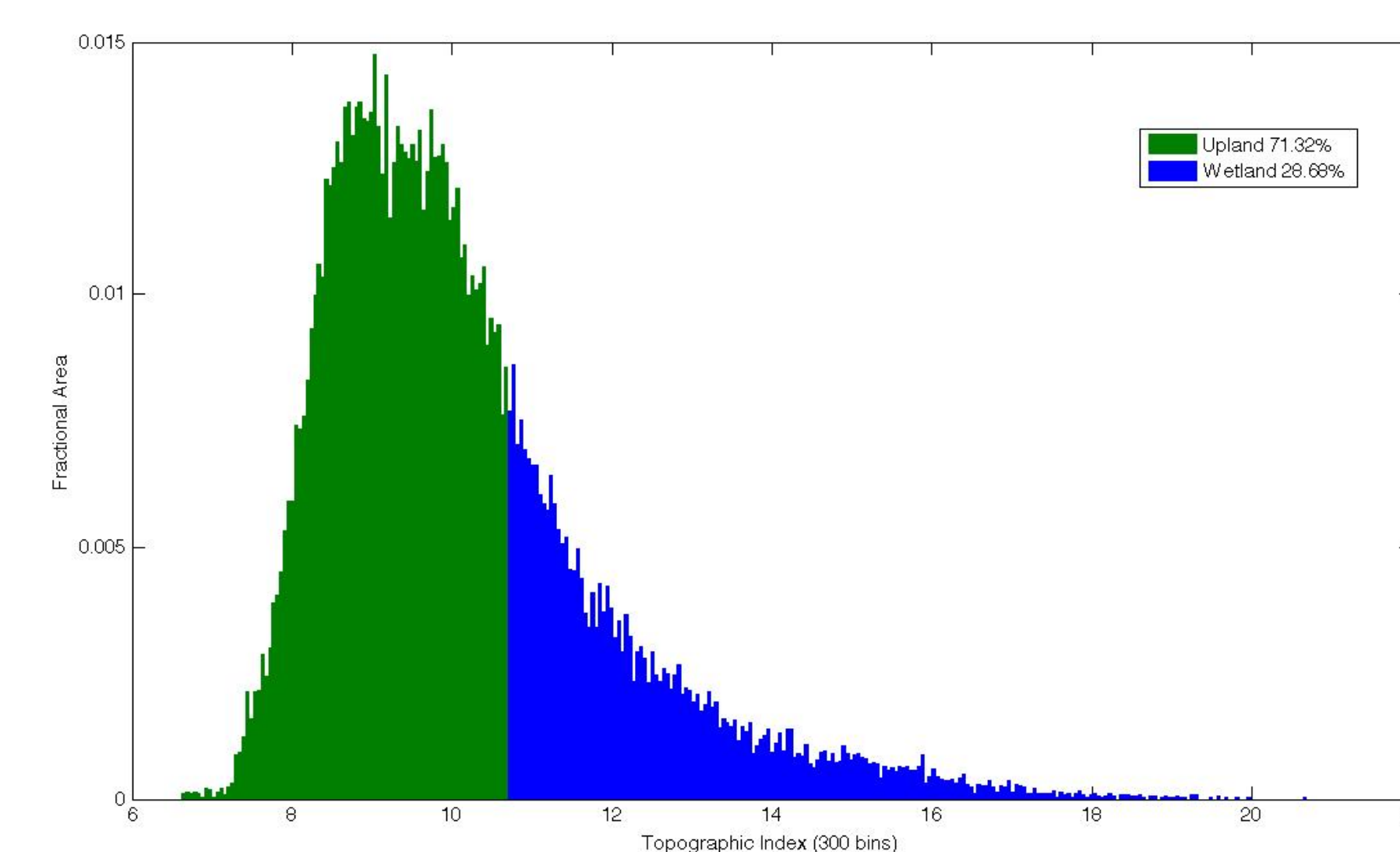


Figure 5. A histogram of the topographic indices of the smoothed 6 km² region surrounding the WLEF site. The blue shaded portion sums to 28.68% of the area, and consists of the regions most likely to be saturated, i.e. those most likely to be wetlands.

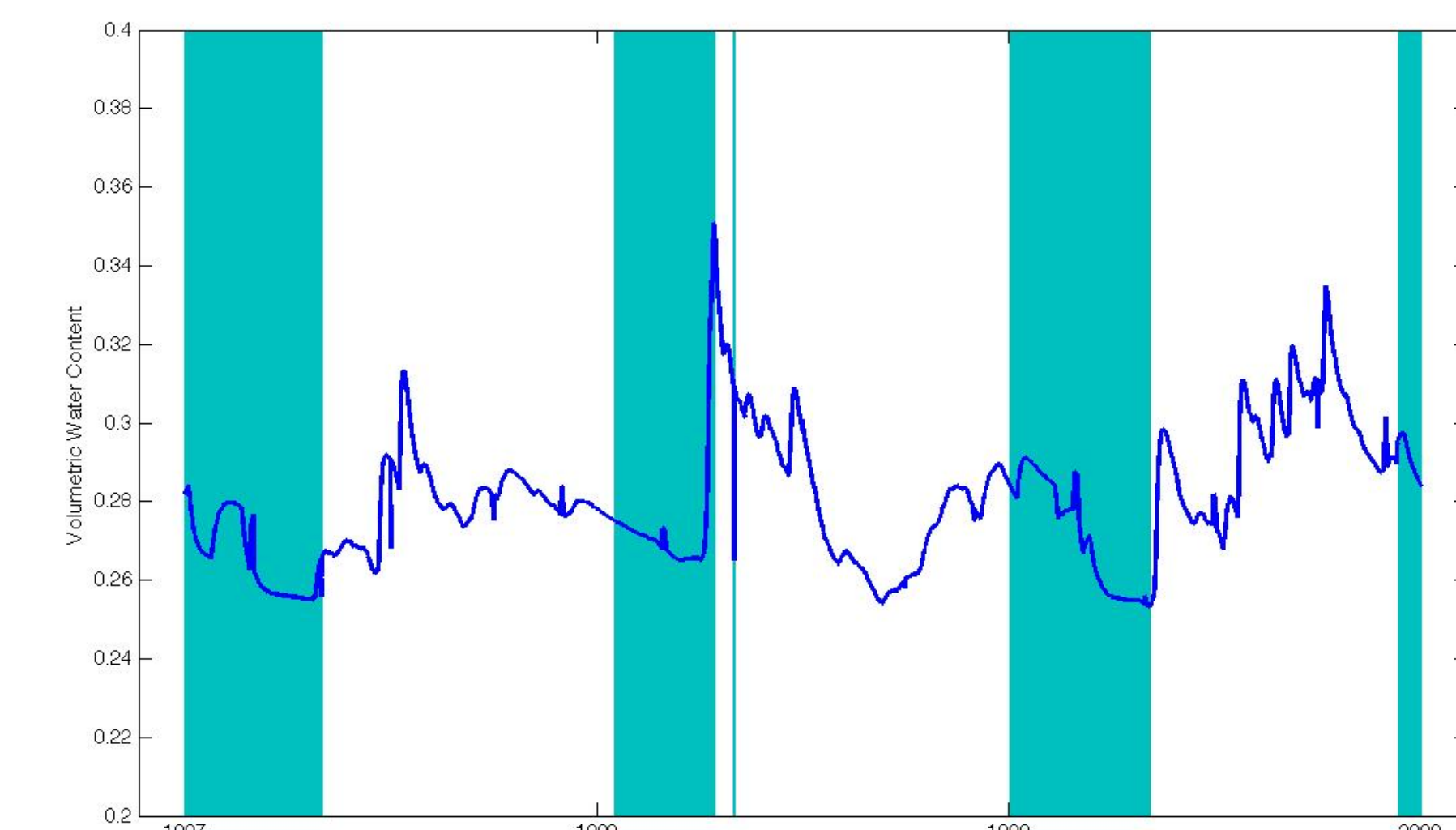


Figure 6. The volumetric water content ($\text{m}^3 \text{H}_2\text{O}/\text{m}^3 \text{area}$) of SiB layer 6 (1.4 m below the surface) at the WLEF site from 1997 to 2000; shading indicates times when soils (not necessarily layer 6) were predicted to be frozen. These values are used to determine the number of bins of topographic index considered saturated; the modal water content was assigned 207 bins, equivalent to 24.91% of the area.

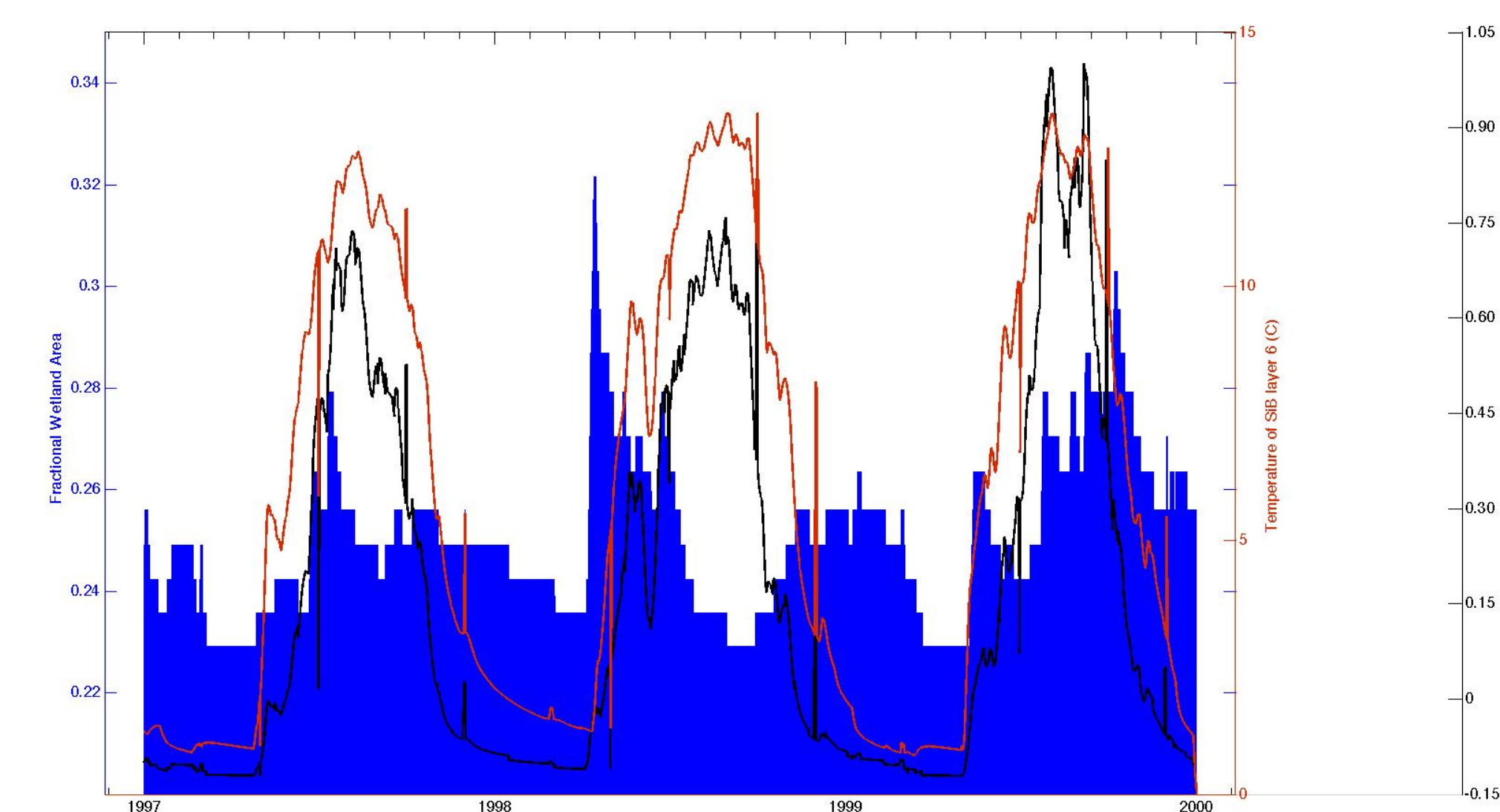


Figure 7. Estimates of fractional wetland area, as predicted by the volumetric water content in SiB layer 6 and the resulting position on the histogram of topographic index, are shown in blue. The temperatures (°C) of SiB layer 6 are shown in red. Estimates of the wetland methane flux ($\text{mg m}^{-2} \text{hr}^{-1}$) are shown in black. The methane flux was calculated using Arrhenius-type equations for the biological production and consumption of methane.

Equation 1. Arrhenius-type equations for the biological oxidation and respiration of methane. Methane respiration is limited to wetland areas, while oxidation occurs throughout the cell. Values of k reflect factors affecting methane production and consumption other than wetland area and temperature, such as pH, redox potential, and the availability of labile carbon; they may be considered as tuning parameters.

Discussion

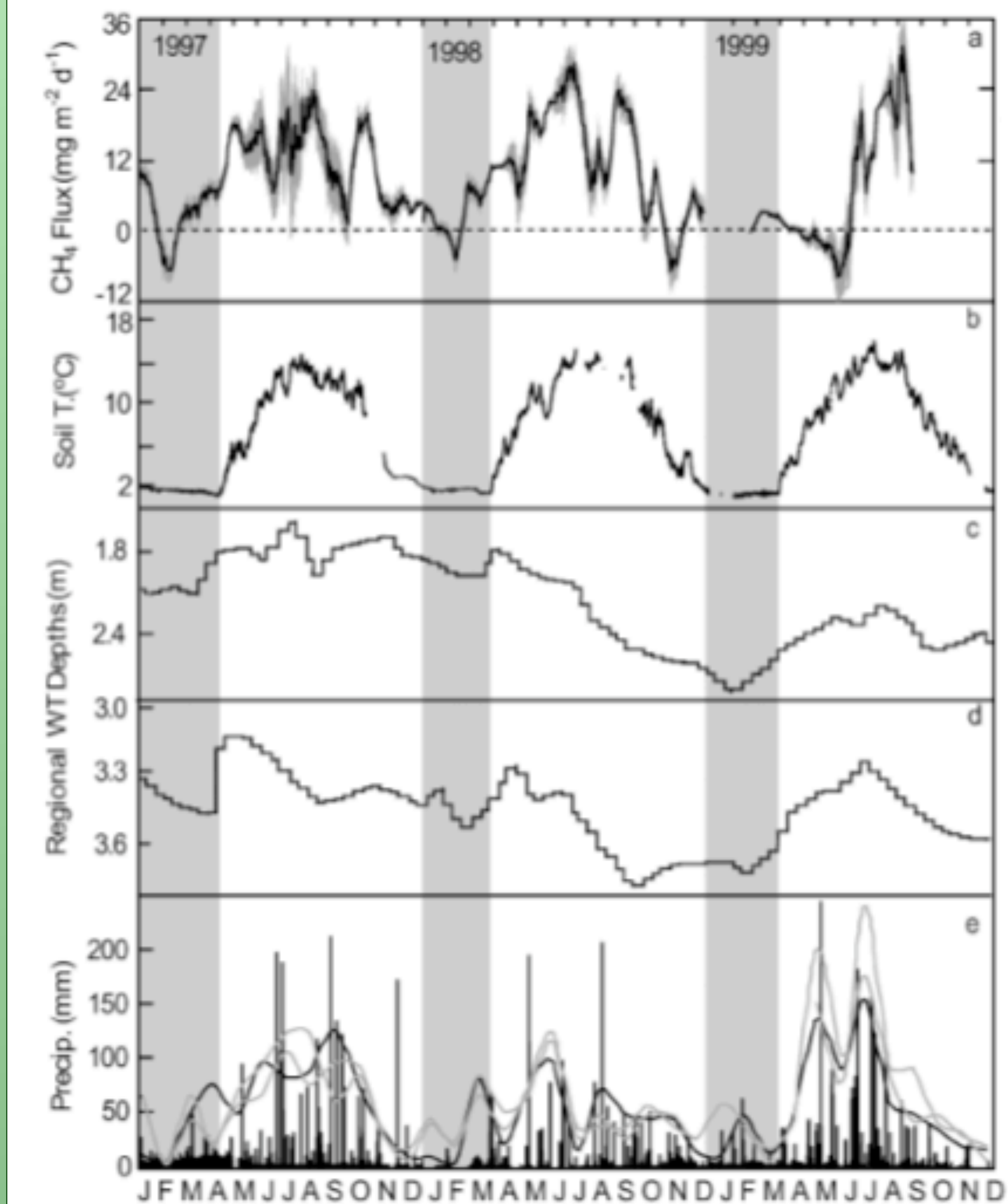


Figure 8. (a) A 2-week running average (the black line) and the standard error (shading) of the CH_4 flux measured at the WLEF site from 1997–1999. Light gray shaded bars indicate periods where the soil temperatures at 20 cm were $<1^\circ\text{C}$. (b) Record of soil temperatures at 20 cm depth. (c, d) Water table depth measured at two wells in the area. (e) Hourly precipitation. Figure from Werner et al., (2003).

Conclusion

This is a novel approach to modeling wetlands and their methane emissions. The method is simple computationally, and relies only on factors which may be determined with reasonable confidence for a GCM grid-cell. The use of the topographic index allows the representation of spatial variability within the grid-cell, without inaccurate and complex models of water table depth (models which commonly neglect topographic variability, despite their complexity). This approach also avoids the explicit representation of phenomena like ebullition, and plant vascular transport, phenomena which are difficult to assess on large spatial scales.

This model is not, as yet, incorporated into a land surface model. Once it has, it may be useful for investigating the dynamics of atmospheric methane concentrations and feedbacks between climate and methanogenesis.

References

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