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Using Equal-Area Quadratic Splines to Compute Depth-Weighted Averages of Soil Chemical Parameters

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Outline

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- Equal-Area Quadratic Splines
- My Research
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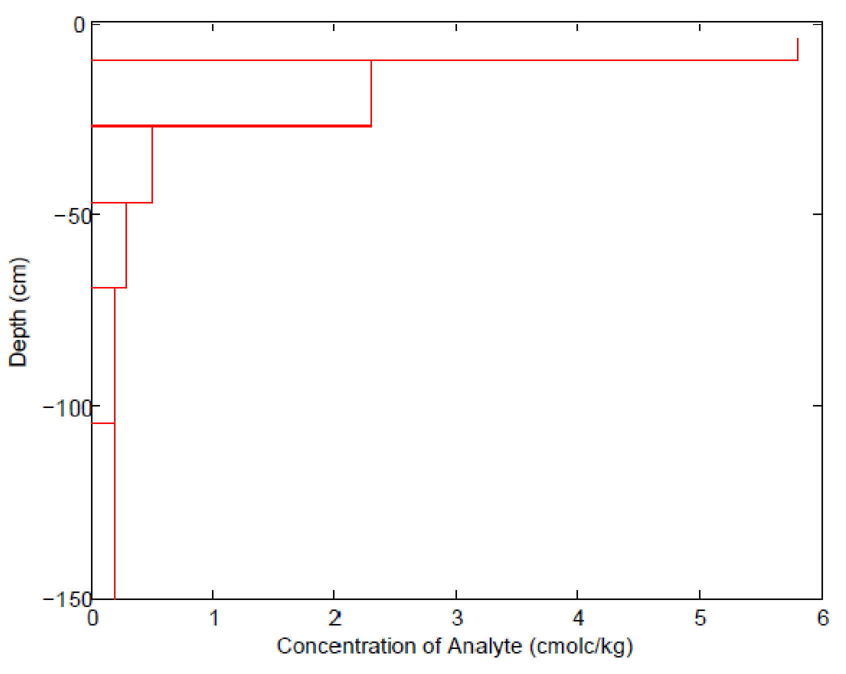
- Summary

Introduction

- For traditional soil sampling:
  - Bulk sample is taken in each horizon
  - Bulk sample is assumed to represent the average value for the soil attributes of that horizon
  - Discontinuous step function is produced

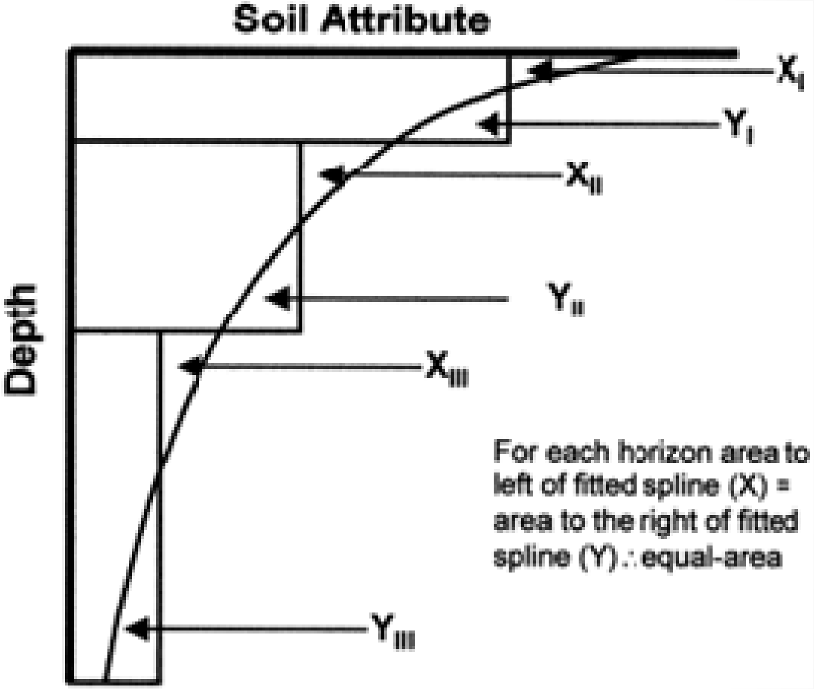


Historical Perspective

- In general, soil attributes vary continuously with depth in the soil profile (Russell and Moore, 1968)
- Various methods have been utilized in an attempt to more accurately model soil parameters in the profile
- Proposed methods to make bulk horizon data more continuous with depth:
  - Freehand curves (Jenny, 1941)
  - Exponential decay functions (Brewer, 1968; Russell and Moore, 1968; Moore et. al, 1972)
  - Linear regression (Campbell et. al, 1970)
  - Polynomials of various degrees (Campbell et. al, 1970; Colwell, 1970)

Equal-Area Quadratic Splines

- Consists of a series of local quadratic polynomials that join at “knots” located at the horizon boundaries (Bishop et. al, 1999)
- Area to the left of the fitted spline curve is equal to the area to the right of the curve (Ponce-Hernandez, 1986)
- Mean value of each horizon is maintained by the spline fit
- Minimizes the true mean squared error (Bishop et. al, 1999)



Equal-Area Quadratic Spline
(Ponce-Hernandez et al.,1986)

Spline Fitting

- The continuous function f(x) is unknown and must be estimated from the horizon data
- Spline fitting consists of choosing f(x) that minimizes:

$$\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{f_i})^2 + \lambda \int_{x_0}^{x_n} [f^{(m)}(x)]^2 \, dx$$

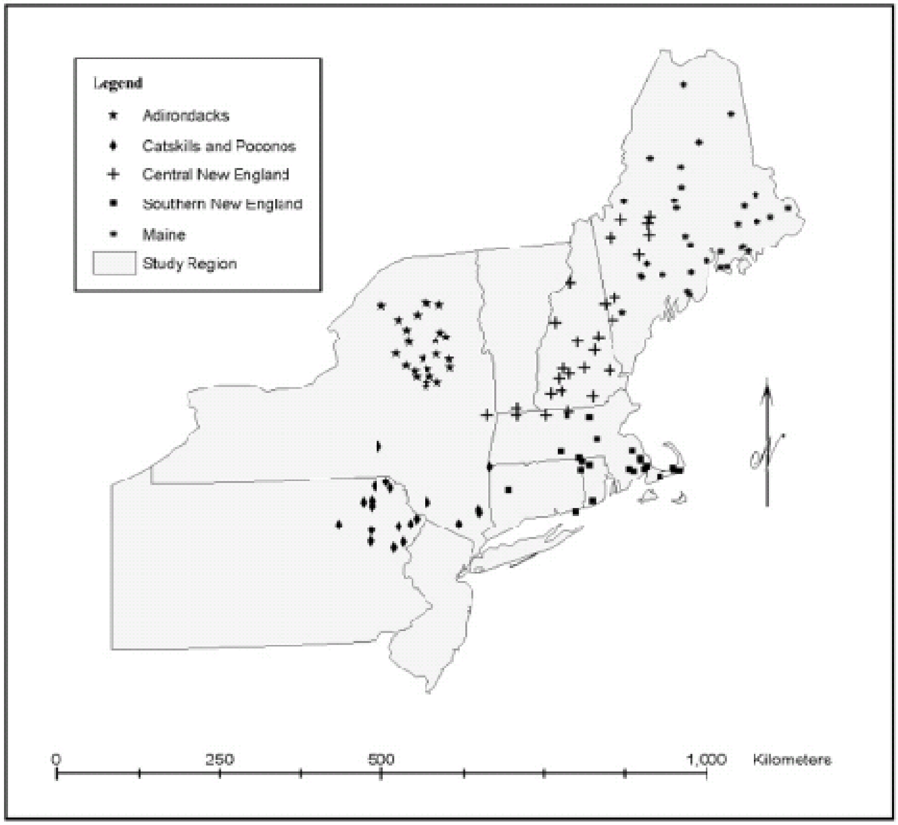
- First term represents "goodness of fit"
- Second term measures the "roughness"
- Parameter λ controls the trade-off between fidelity and roughness penalty

Previous Studies

- For soil profiles in Australia, EAQS performance compared to:
  - Exponential decay functions
  - 1st and 2nd degree polynomials
- Predicting depth functions for
  - pH, electrical conductivity, clay (%), sand (%), organic carbon, and water content
- “Results clearly indicated the superiority of equal-area quadratic splines in predicting depth functions” (Bishop et al., 2009)
- EAQS also effective for mapping continuous depth functions of soil carbon storage and available water capacity (Malone et al., 2009)

My Research

- Keck Project (2001): Resurvey of watersheds previously conducted under the EPA's Direct/Delayed Response Program (DDRP) in 1984
- Study the continuing acidification of organic soils in the region (Warby et. al, 2007)



My Research (cont.)

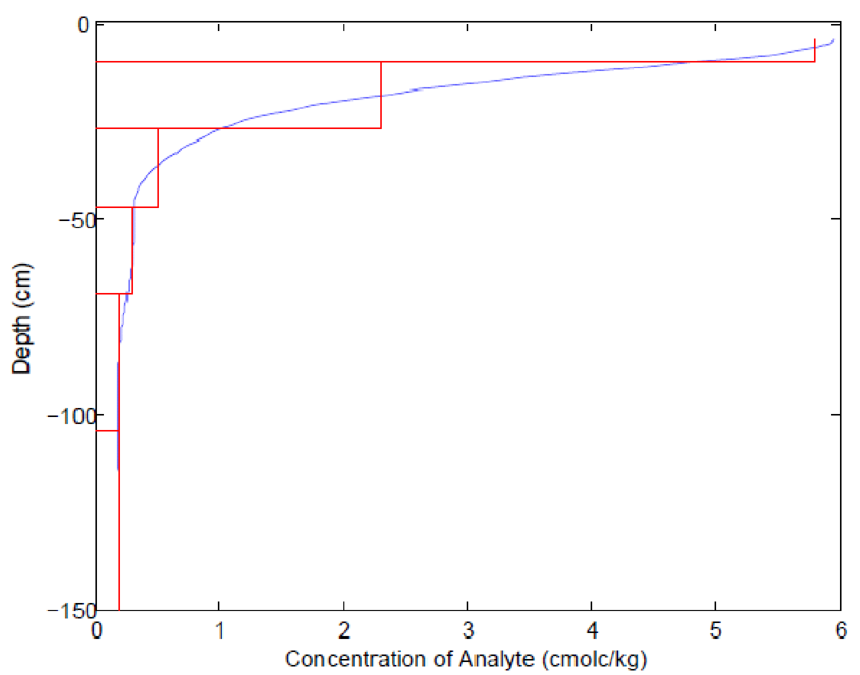
- O_a horizon was selected for analysis because it is not diagnostic of any specific soil type for the region sampled (Warby et. al, 2007)
- Goals of my research:
  - Use EAQS to predict soil depth functions based on bulk horizon data
  - Use EAQS to compare mineral soil data from 1984 with the Keck data collected in 2001
  - Assess the effects of changes in acidic deposition on chemical properties of mineral soils, over time, on a regional scale

MATLAB Program #1

- Goal: Use EAQS to predict soil depth functions based on bulk horizon data
- User input program:
  - Desired watershed to be analyzed
  - Specific analyte to be modeled
  - Desired λ value
- Program reads the appropriate information from the spreadsheet containing data collected during sampling
- Program is designed to only analyze the mineral soil horizons in the desired watershed
- Output:
  - y-fit
  - s-bar
  - true mean squared error

Program Output

- Plot the continuous function computed by the spline fitting program
- Plot the bulk horizon concentration data as a discontinuous step function
- Use Simpson's Rule to calculate a mean concentration of analyte in user specified segment of the mineral soil profile



MATLAB Program #2

- Goal: Use EAQS to compare mineral soil data from 1984 with the data collected in 2001
- Modification of the original MATLAB program
- Analyze all watersheds in Adirondacks
  - DDRP Samples (n = 49)
  - Keck Samples (n = 28)
- Four analytes
    - Al, K, Ca, Mg
- Use Simpson's Rule to compute depth-weighted averages for analytes in mineral soil

Example Output

First 10 ADK Watersheds from DDRP Dataset. Mineral soil depth:10 cm.

DDRP Watershed	Al (cmolc/kg)	Ca (cmolc/kg)	K (cmolc/kg)	Mg (cmolc/kg)
1	13.028	0.321	0.666	0.331
2	2.820	0.086	0.031	0.043
3	3.170	2.460	0.038	0.206
4	7.872	0.135	0.059	0.094
5	4.423	0.123	0.038	0.037
6	2.719	0.090	0.035	0.025
7	0.417	1.342	0.047	0.445
8	5.172	0.363	0.041	0.057
9	0.958	0.265	0.005	0.024
10	13.010	0.392	0.057	0.085

Results

- Compare new datasets using unpaired t-test

P-values from the unpaired t-test.

Analyte	6 cm	8 cm	10 cm
Al	0.537	0.699	0.262
Ca	0.025	0.031	0.034
K	0.308	0.419	0.504
Mg	0.027	0.031	0.033

- Based on $\alpha = 0.05$:
  - Null hypothesis accepted for Al and K
  - Rejected for Ca and Mg
- Increasing trend in p-values as thickness of mineral soil increases

Discussion

- EAQS are useful tool for predicting soil depth functions based on bulk horizon data
- EAQS allow for comparison of chemical analytes in mineral soils based on depth data
- Applicable for a wide range of soil chemical parameters
- Future research to examine the effects of changes in acidic deposition on chemical properties of mineral soils, over time, on a regional scale

Discussion (cont.)

- Turkey Lakes Watershed Study (Ontario, Canada)
  - Identified as an area of maximum critical load for S and N deposition
  - "Our retrospective soil study provided no evidence of soil acidification or base cation depletion for the mineral soil at the TLW. There were no significant declines from 1986 to 2003 and 2005 in site mean pH, exchangeable Ca, Mg, and K concentrations." (Hazlett et al., 2011)
  - Inputs due to mineral weathering are able to replace outputs from leaching and tree uptake
- Results from Adirondacks show no significant difference for K, but provide evidence of changes in Ca and Mg

Future Applications

- For this study:
  - Data analysis limited for this presentation
  - Analysis of more soil chemical parameters
  - Expand analysis to other regions in the study
  - Assessment of soil chemical change on regional scale
- In general:
  - Useful for predicting soil depth functions
  - Applicable to wide range of chemical parameters
  - Applicable at any study site

Summary

- EAQS are very useful tool for predicting soil depth functions based on bulk horizon data
- Ability to examine the effects of changes in acidic deposition on chemical properties of mineral soils, over time, on a regional scale
- Preliminary analysis shows evidence of continued soil acidification in the Adirondacks.
- More comprehensive analysis of dataset in the future.
- Tremendous potential for future use of EAQS on wide range of soil chemical parameters.

Acknowledgements

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References

- Bishop, T.F.A., McBratney, A.B., Laslett, G.M., 1999. Modelling soil attribute depth functions with equal-area quadratic smoothing splines. Geoderma 91, 27-45.
- Brewer, R., 1968. Clay illuviation as a factor in particle-size differentiation in soil profiles. Transactions of the 9th International Congress of Soil Science 4, 489–499.
- Campbell, N.A., Mulcahy, M.J., McArthur, W.M., 1970. Numerical classification of soil profiles on the basis of field morphological properties. Australian Journal of Soil Research 8, 43–58.
- Colwell, J.D., 1970. A statistical–chemical characterization of four great soil groups in southern New South Wales based on orthogonal polynomials. Australian Journal of Soil Research 20, 221–238.
- Jenny, H., 1941. Factors of Soil Formation: a System of Quantitative Pedology. McGraw Hill, New York and London.
- Malone, B.P., McBratney, A.B., Minasny, B. and G.M. Laslett, 2009. Geoderma Volume 154, Issues 1-2, 15 December 2009, Pages 138-152
- Ponce-Hernandez, R., Marriott, F.H.C., Beckett, P.H.T., 1986. An improved method for reconstructing a soil profile from analyses of a small number of samples. Journal of Soil Science 37, 455–467.
- Russell, J.S., Moore, A.W., 1968. Comparison of different depth weightings in the numerical analysis of anisotropic soil profile data. Transactions of the 9th International Congress of Soil Science 4, 205–213.
- Warby, R.A.F., Johnson, C.E., and Driscoll, C.T. Continuing acidification of organic soils across the northeastern U.S.A.: 1984-2001, Soil Science Society of America Journal, 2007.

Questions?