Workshop 2_Nonlinear Models

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Objectives

The primary objectives of applying a nonlinear least squares regression and bootstrapping approach to our long-term net ecosystem exchange dataset are:
1. Creating a data frame to store monthly parameter values.
2. Writing a function to fit the model and extract parameters.
3. Writing a loop to fit monthly curves and add parameters to a data frame.
4. Bootstrapping for error estimation.

Methods

The Environmental Measurement Station Eddy Flux Tower (EMS) has taken atmospheric measurements including carbon dioxide, methane and other atmospheric trace gasses since 1990. It is located in the study site Harvard Forest, latitude: 42.53, longitude: -72.19 at elevation 330 (Fig. 1).

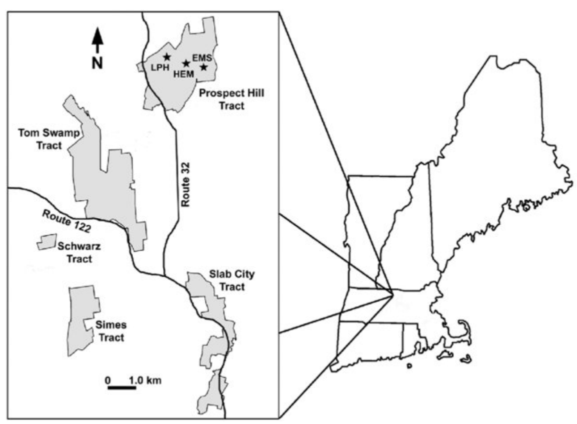

Fig. 1. Map of Harvard Forest and New England with the different research towers mapped including the Environmental Measurement Site (EMS), Hemlock (HEM) and Little Prospect Hill (LPH) flux towers.

The dominant vegetation at EMS includes transition hardwood, white pine (Pinus strobus) and Eastern hemlock (*Tsuga canadensis*). The climate is cool and moist and has an annual mean precipitation of 110cm, distributed evenly throughout the year. This data analysis looks to apply nonlinear models and bootstrapping in R to the EMS night dataset from harv (night) to fit monthly temperature response curves. To fit the nonlinear model, we use the Arrhenius Approach equation, where a is the base respiration rate when air temperature is 0 degree C and b is an empirical coefficient:

$$NEE = aexp^{b*TA}$$

Photosynthetic Potential
Our dataset is looking at the net ecosystem exchange (NEE) from the environment, which is a measure of the net exchange of carbon between an ecosystem and the atmosphere. As well as photosynthetically active radiation (PAR), the spectral range of solar radiation (400-700nm) that photosynthetic organisms are able to use in photosynthesis. The harv dataframe is divided into two files: day (PAR>0) and night (PAR == 0). The dataset was first analyzed fitting the light response curves to net ecosystem exchange to understand annual patterns of ecosystem photosynthetic potential and respiration rates in temperate mixed forests. For this we use the Michaelis-Menten Approach:

$$NEE_{day} = R_{eco} - \frac{(\alpha\phi P_{max})}{(\alpha\phi + P_{max})}$$

Which includes three parameters: apparent quantum efficiency, maximum ecosystem CO2 uptake and r, the ecosystem respiration.

Ecosystem Respiration
Ecosystem respiration is the sum of all respiration occurring by the living organisms in a specific ecosystem. Organisms within the ecosystem use the process of respiration to convert organic carbon to carbon dioxide, which plants may take up through photosynthesis. The results and discussion below is focusing on the night dataframe, which uses parameters base respiration rate when air temperature is 0 degree C and an empirical coefficient.

Results

To measure the relationship between the night data and net ecosystem exchange. The nls (nonlinear least squares) tool package allows for running nonlinear modeling and bootstrapping, the bootstrapping of the data allows for random sampling and replacement of the data which tests for accuracy and robustness of the data collected. We checked our data in multiple ways to see if it met our assumptions (Fig. 1).

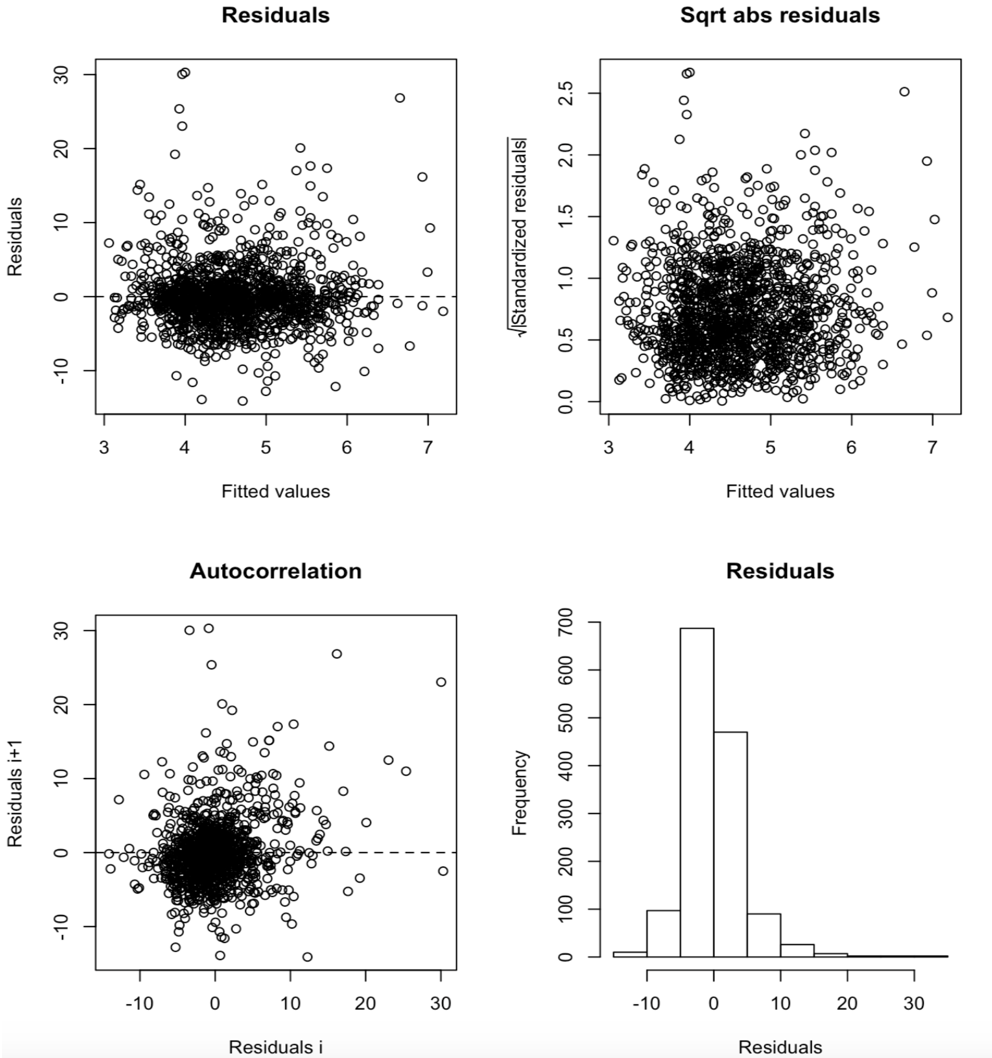

Fig. 1 Four plots checking if the night data meets assumptions: a) Residuals vs fitted values, testing for constant variance; b) Standardized residuals; c) Autocorrelation; d) Histogram, testing for normality.

Nls requires that we set our parameters, which for the night data we have defined "a" and "b" parameters as well as find the starting values of them. The results are listed in table 1 for both parameters including the p-value and standard error. We then use the `selfStart` function to calculate our initial values to run our model (table 1). Afterward, we can fit our bootstrap and we set it to run 100 times (table 2).

Table 1 Initial start parameters of a and b.

a	b
4.844482	-0.014762

Table 2 Median of bootstrap estimates and percentile confidence intervals.

	Median	2.5%	97.5%
a	2.08376110	1.51565003	2.85922725
b	0.04411342	0.02700372	0.05970701

Once we set our bootstrap and had it extract starting values we added our bootstrap to our data frame and we merged the data frames to get our model in table 3.

Table 3 Median of bootstrap estimates and percentile confidence intervals.

Month	a	b	a.pvalue	b.pvalue	a.est	b.est	a.se	b.se
1	1.282263	0.02790180	1.525352e-220	3.018140e-13	1.282282	0.02847105	0.03917854	0.004242180
2	1.235765	0.03136320	3.371053e-312	1.048487e-17	1.239195	0.03185366	0.02996198	0.003843031
3	1.100977	0.03822106	0.000000e+00	3.384413e-36	1.101165	0.03794464	0.02659603	0.004251976
4	1.270271	0.04778224	9.364373e-119	2.004514e-28	1.272670	0.04799861	0.06198774	0.005033297
5	1.755597	0.05711204	5.909270e-83	1.960327e-57	1.754641	0.05721296	0.09393330	0.003741951
6	2.400125	0.03898796	5.739331e-21	1.561759e-10	2.427486	0.03889007	0.30775283	0.007229586
7	2.005208	0.04542368	2.136097e-11	4.612000e-09	2.076157	0.04417668	0.33958539	0.008769017
8	4.798788	-0.01422836	4.284395e-10	1.053243e-01	4.853229	-0.01373271	0.95981580	0.010482134
9	1.821047	0.03695793	3.277657e-23	2.662523e-09	1.850328	0.03653687	0.22161616	0.007692262
10	1.679584	0.03924262	1.563406e-84	7.956977e-20	1.689766	0.03890445	0.09218997	0.004786513
11	1.674095	0.05336393	9.956529e-262	3.163543e-64	1.675149	0.05302278	0.04447297	0.003217928
12	1.641407	0.03461697	6.783500e-315	5.508818e-19	1.646256	0.03440977	0.03995011	0.004778240

Discussion

Our nonlinear least squared model allowed us to model and make projections of our data while testing for robustness of our data. We plotted monthly temperature response curves using the night data from harv (night), using the Arrhenius Approach equation:

$$NEE = aexp^{b*TA}$$

From this we could analyze and understand annual patterns of net ecosystem exchange and respiration rates in temperate mixed forests using the Harvard Forest site as our model.