

LakeN

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Introduction

This model was written as a project for course 68806 Eco-hydrologic modelling with R. This model illustrates the annual N cycle in a lake in northern Israel, and simulates the transitions from oxydized species into reduced species.

Background

Anthropogenic effects of the recent years has largely affected the nitrogen cycle during the last decades. Increased N inputs, primarily as river-born nitrate, originating in soils, encourage eutrophication, anoxic conditions and blooms of harmful algae, interrupting the ecological cycle.

The nitrogen cycle includes several key processes, which include its cycling between several species and affect its bioavailability. Rivers are efficient N sinks, but in its inorganic forms, it is removed from the water through assimilation and adsorption onto sediments. In addition, the precipitation of organic N and denitrification are two major processes that remove N from the water. In the studied lake, an N-fixing algae of the cyanobacteria phylum appeared for the first time during the autumn of 1994. It reappears every year since that time, and was recently accompanied by another cyanobacteria specie since 2005. This dramatic change in lake ecology is the likely result of changes in the availability of water-soluble nutrients, which provided the N-fixing species with a relative ecological advantage.

It is important to remember that the measurement process provides a “snapshot” of lake conditions in a specific day, and that all cooccurring processes create interchanging fluxes of nitrogen between the nitrogen pools. While the modelling of the molecular process is difficult to configure, because it involves complex biological processes, the net transformation of species between pools can be modelled through a “net-gross” approach, where molecular transformations are summed into simplistic, time-dependent processes, that are arithmetically disconnected. If each of these processes is modelled properly, the N cycle can be modelled in terms of net fluxes, without taking into account all possible processes and their complexities.

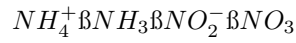
The N cycle in the studied lake

Several key processes dominate the N cycle of the studied lake. These include nitrification, denitrification, the fixation of atmospheric nitrogen by cyanobacteria and N recycling through consumption of primary producer up the food chain. These processes are inherently biologically mediated, and their relative role in the transformation of one species to another greatly depends on physical conditions including radiation and temperature as well as the chemical properties of the lake, which are largely dependent on its limnological cycle. The consideration of these parameters in a limnological perspective is essential for the consideration of the dominant processes and their ecological impact. These processes are briefly described in the section below:

Nitrification

Nitrification includes the oxidation of ammonia into nitrite in a two-stage process mediated by the nitrosomonas bacteria followed by the oxidation of nitrite through the mediation of the nitrobacteria, that can be summarized

as:



This process largely depends on oxygen availability, ambient conditions and the size of bacterial populations. The process has been documented to be carried quickly and directly into nitrate in some years, whereas in others the increase in nitrite preceded the transformation into nitrate by several days and up to a couple of weeks.

The nitrification takes place in oxic conditions, and largely depends on the mixing of the water column during the winter, and is halted in the hypolimnion during the well-stratified conditions that develop from spring to autumn. Nitrification is however possible still possible in the interface of the hypolimnion with the epilimnion, where dissolved oxygen is present to some extent. Nitrate concentrations are highest at the end of January after the mixing of the lake is most effective, as well as additions of from surface runoff. Correspondingly, nitrite and ammonium are low during this interval.

Data preparation

The data is provided in discrete form of concentration measurements. The depths of the measurements are not constant, and the time intervals between measurements are also not constant, and range from several days to several weeks.

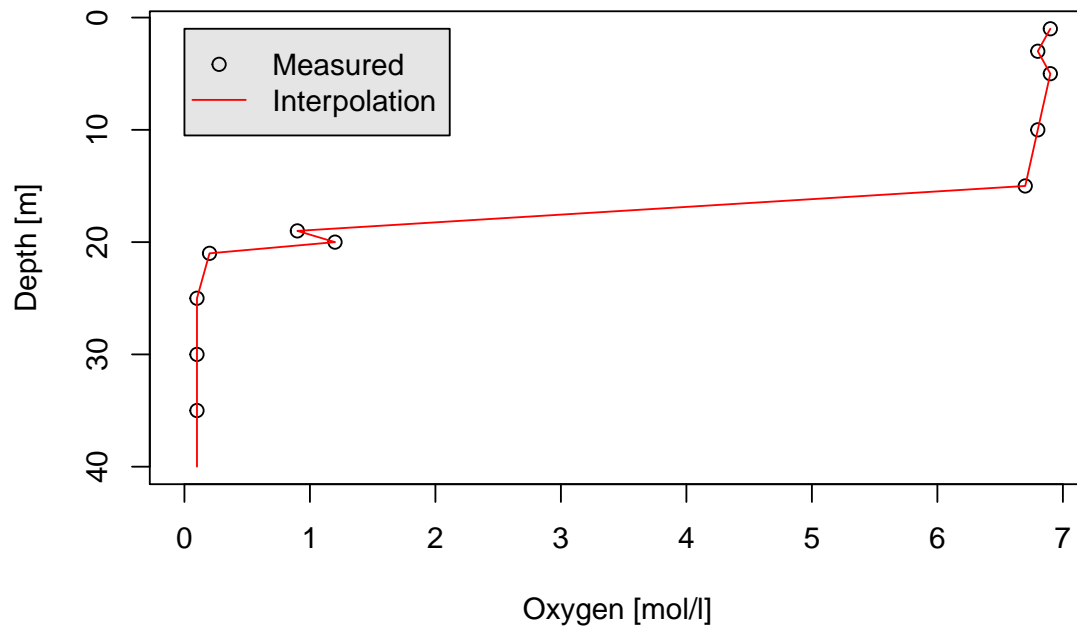
read the data and load relevant libraries

Interpolate the Data into 1 m Intervals

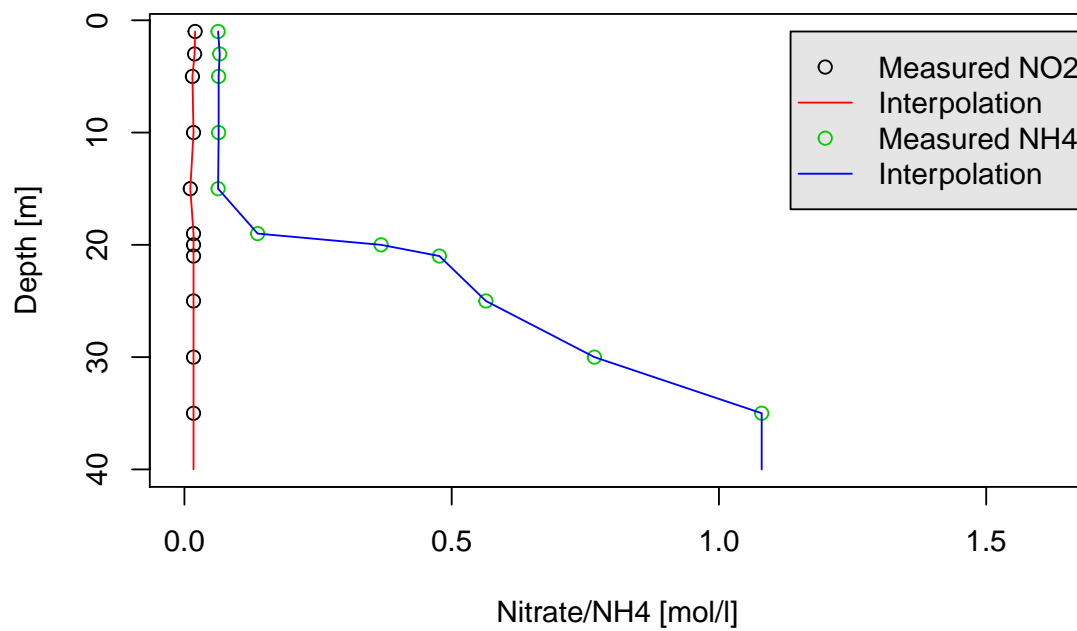
Use the function “depthinterp” to interpolate the data into uniform length for every 1 m. This is essential for later calculating the volume of each depth interval and the mass of each N species measured in this depth.

Demonstrate interpolations of randomly selected data

Oxygen interpolation 2012-11-12



N species interpolation 2012-11-12

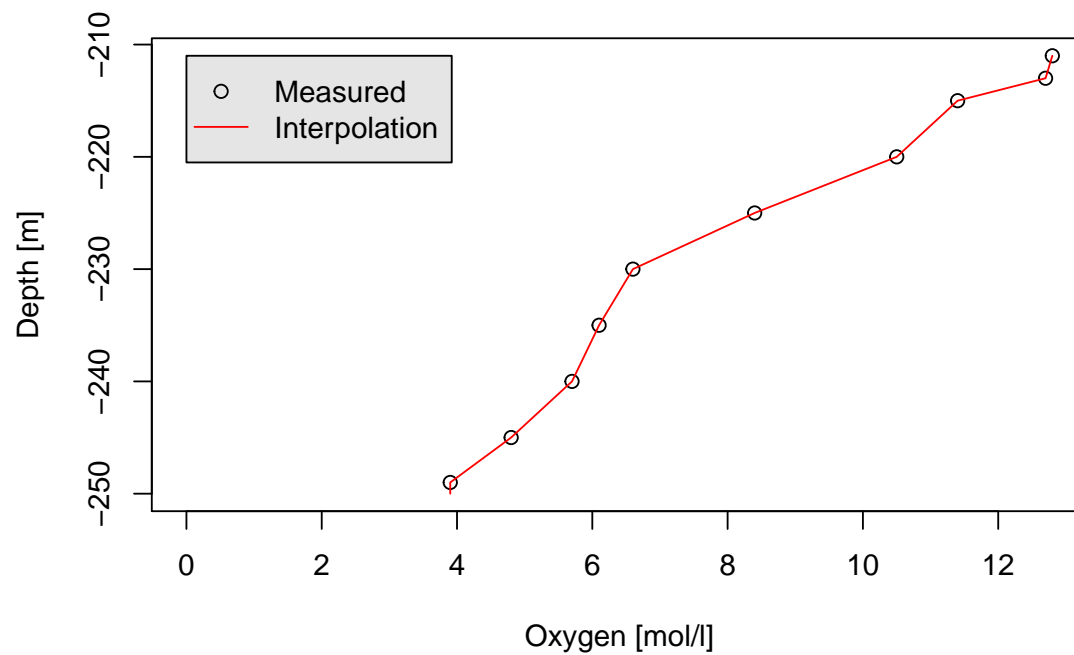


Depth and Level Corrections

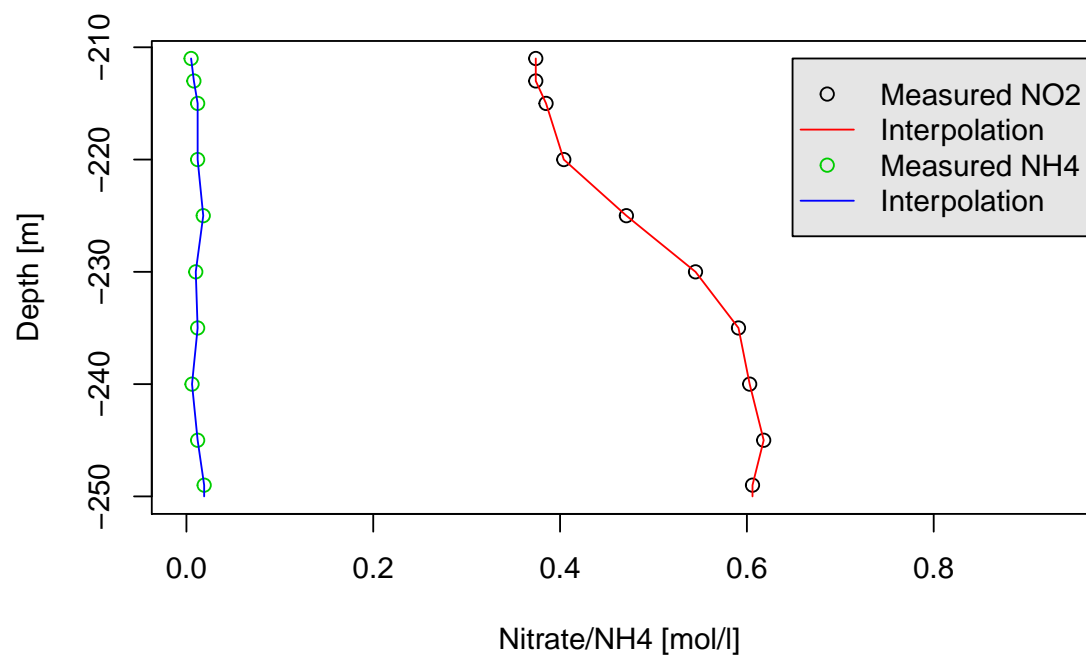
Calculate the appropriate depth for each measurement using available daily level measurements. Use function “realdepth” and use closest day if no level measurement of that day is available. This correction is essential for later calculation of depth to volume and concentration quantification of N species in the lake.

demonstrate the results according to the new depth scale of randomly selected data

Oxygen interpolation 2013-04-02

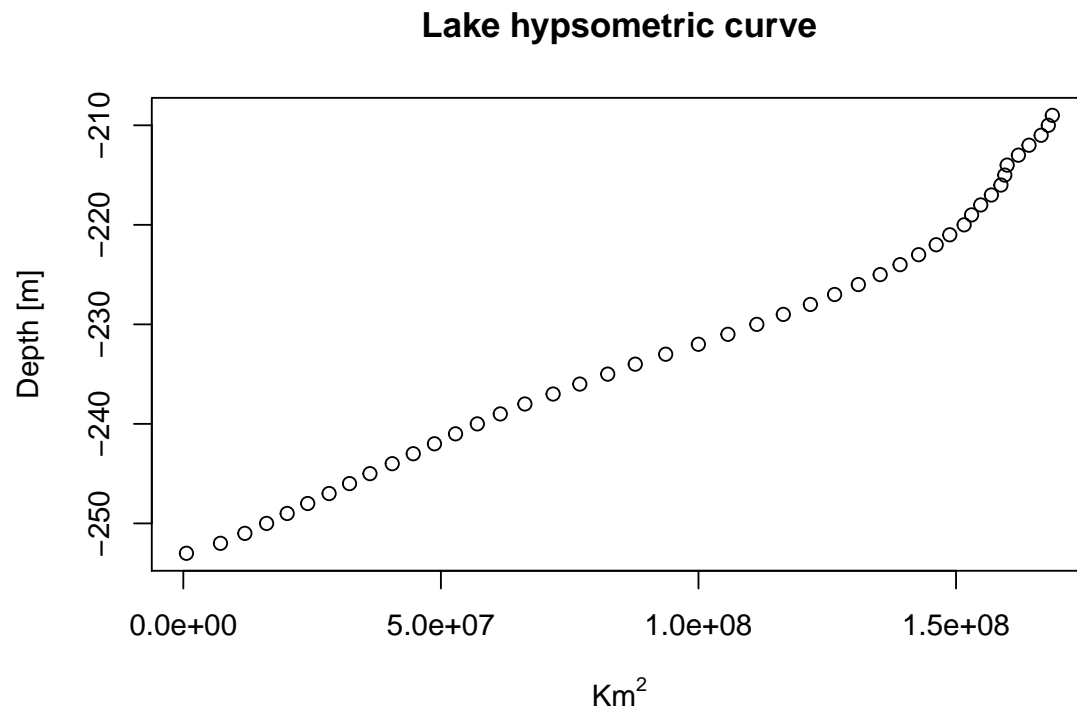


N species interpolation 2013-04-02



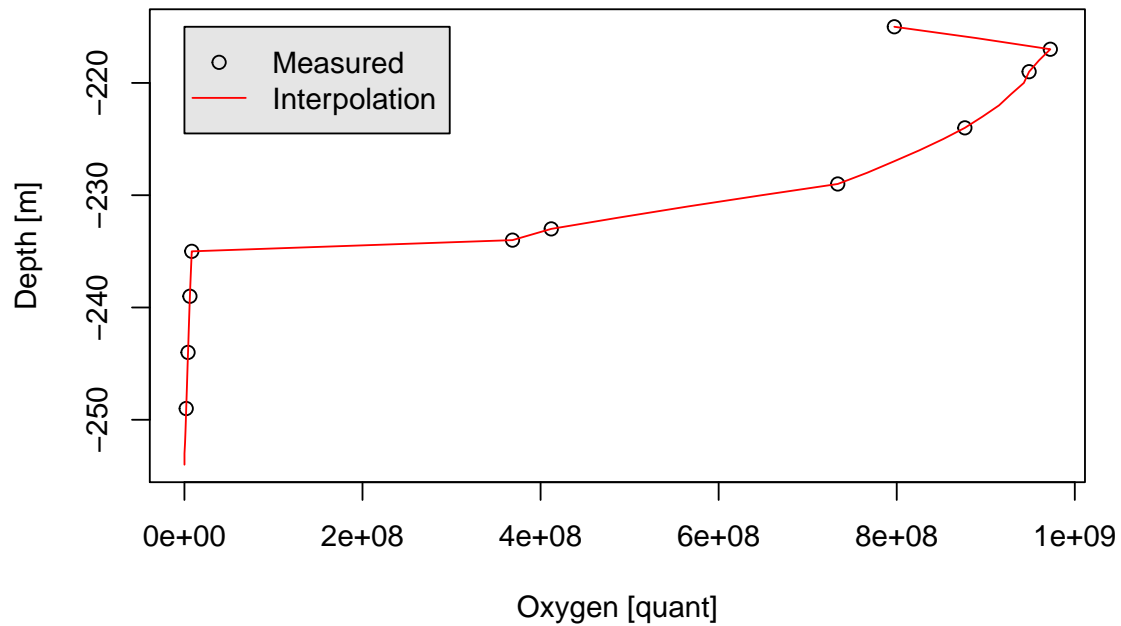
Quantify the data using lake hypsometric curve

The use of concentrations has limitations because it may enhance or demise a processes that is inherently “mass-based”. Quantify the amount of measured species using the hypsometric curve of the lake using function “conctoquant”. Multiply each depth value with its corresponding hypsometric value to

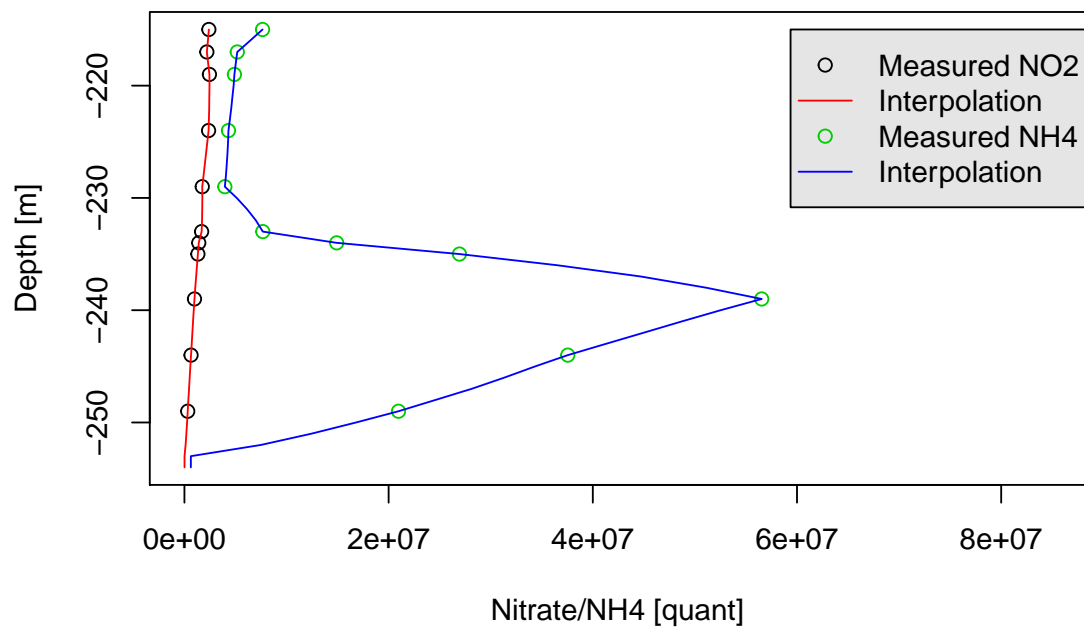


demonstrate the results according to the new depth scale of randomly selected data

Oxygen interpolation 2011-10-23



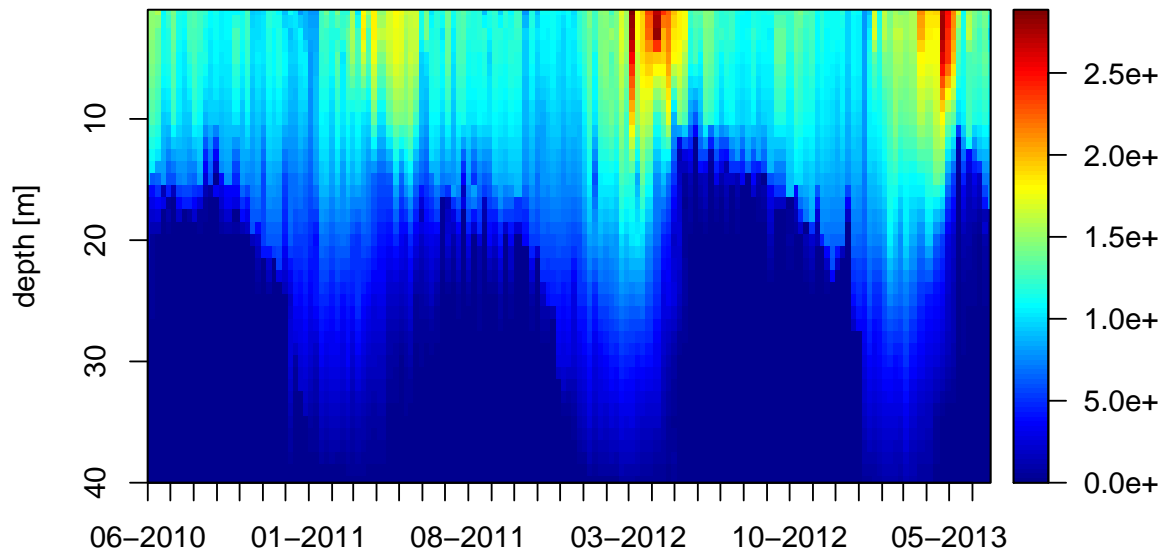
N species interpolation 2011-10-23



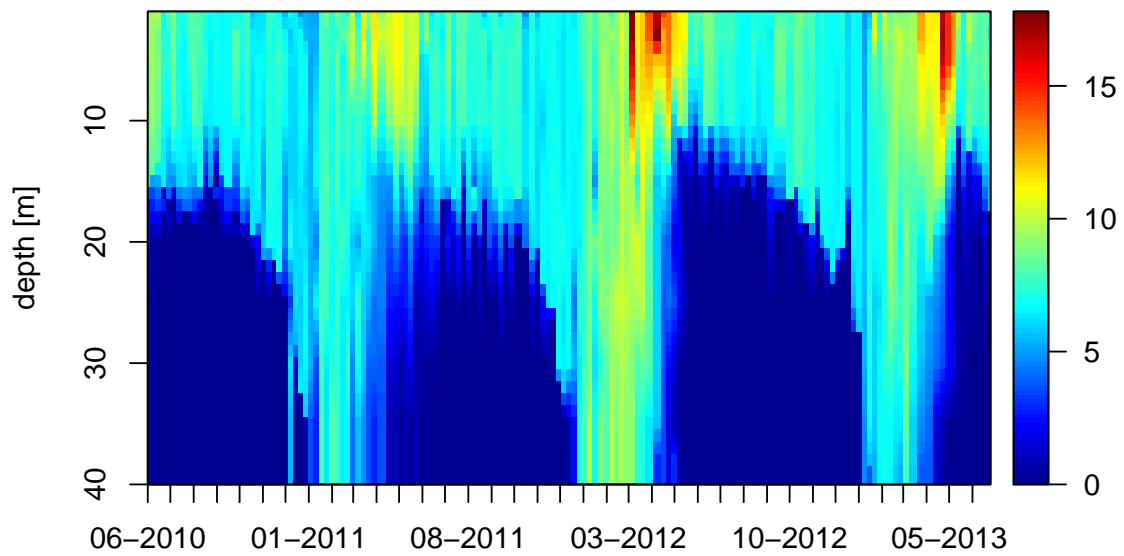
Time series plots

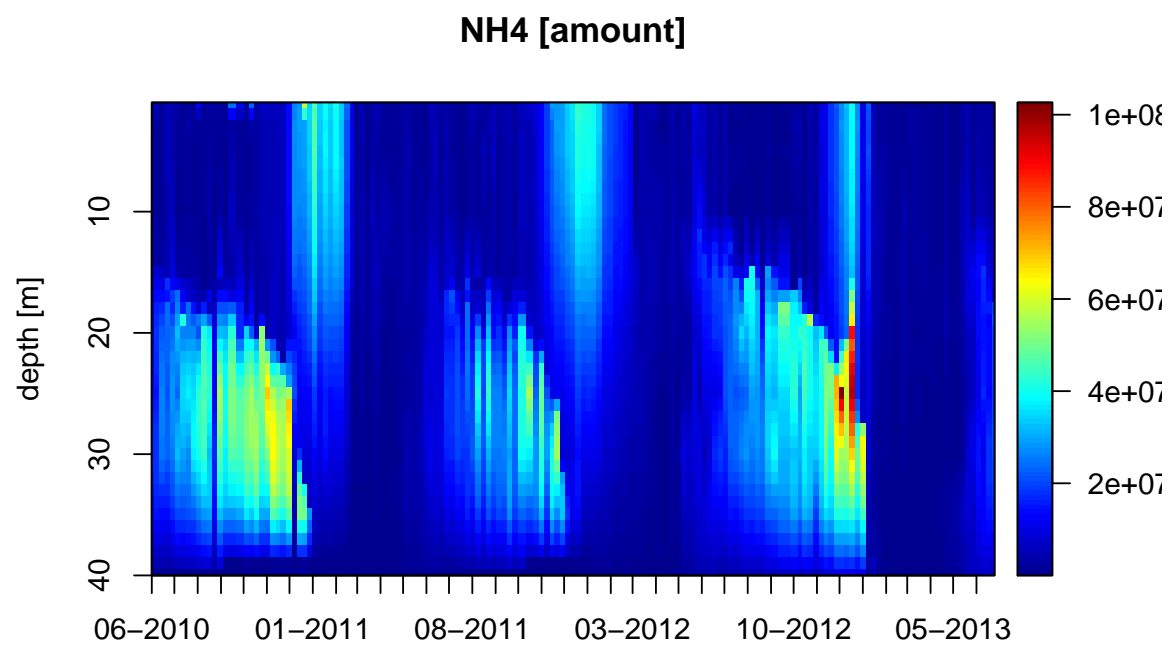
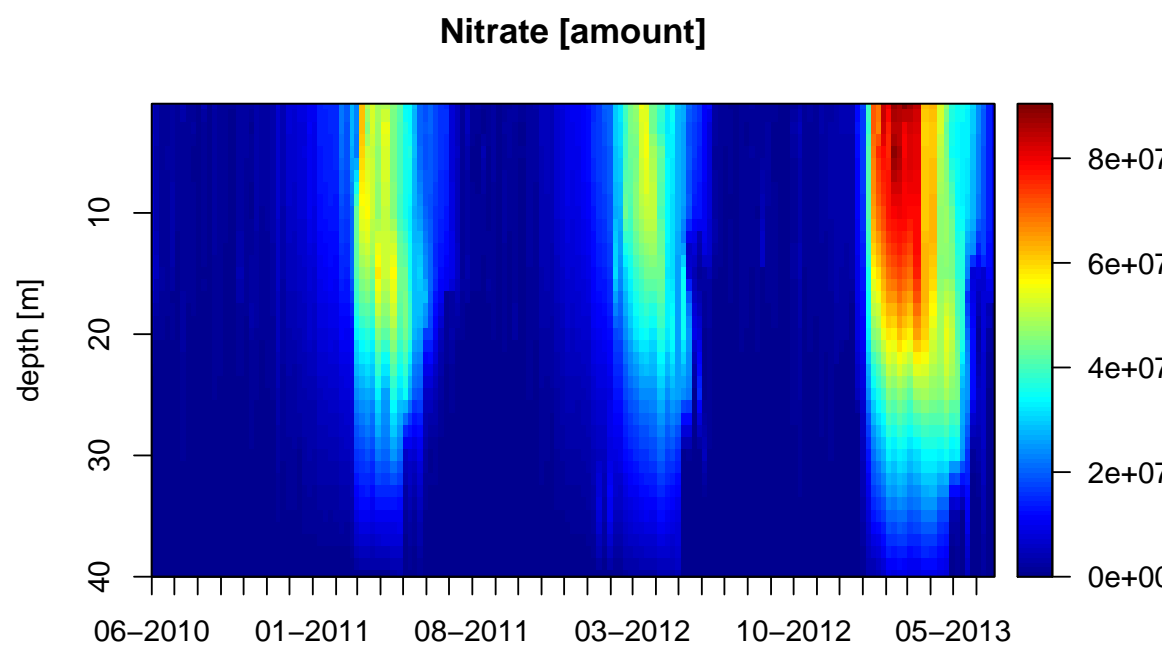
The following plots provide some visual estimation of the data to visualize time-depth processes for further considerations for the modelling of the processes

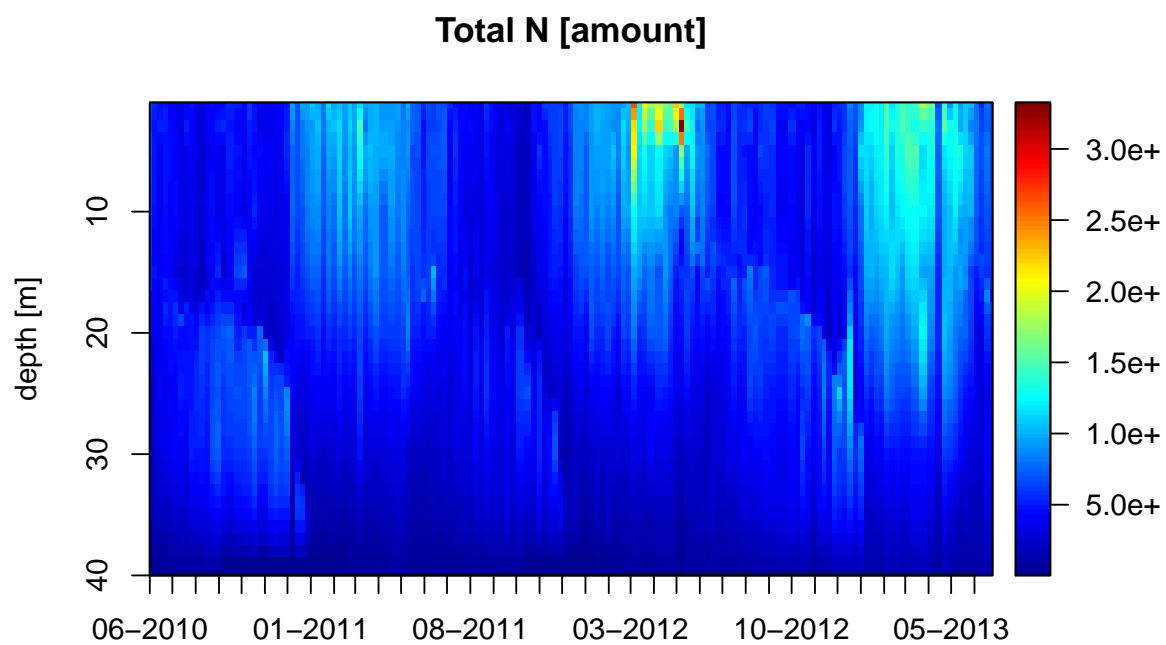
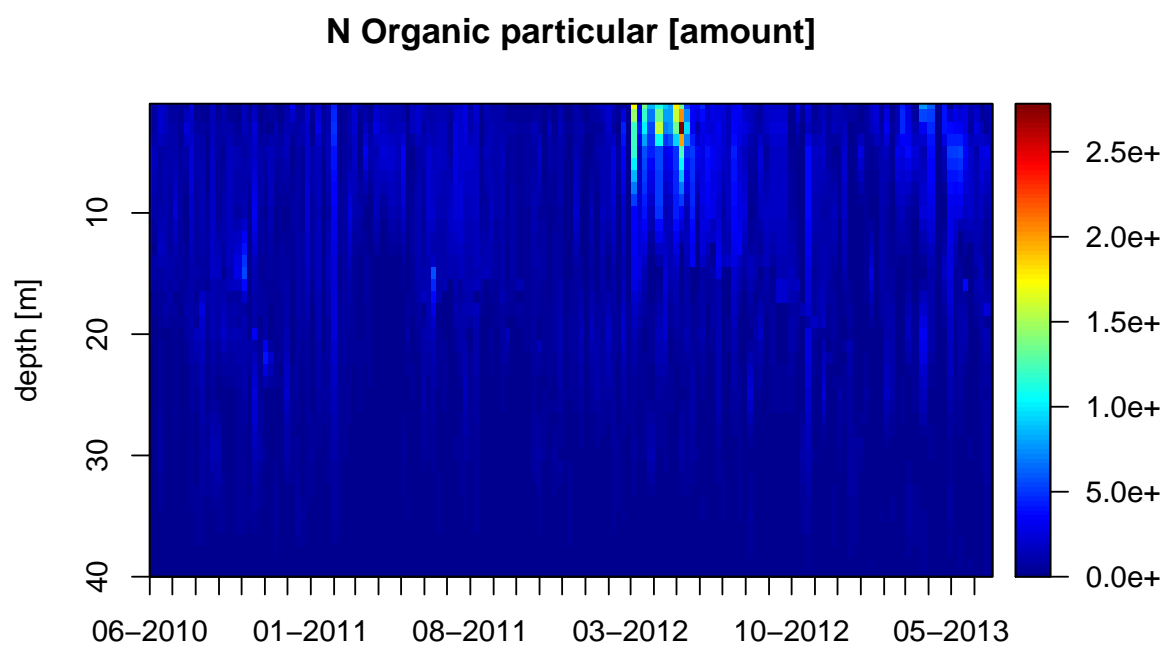
Oxygen [amount]



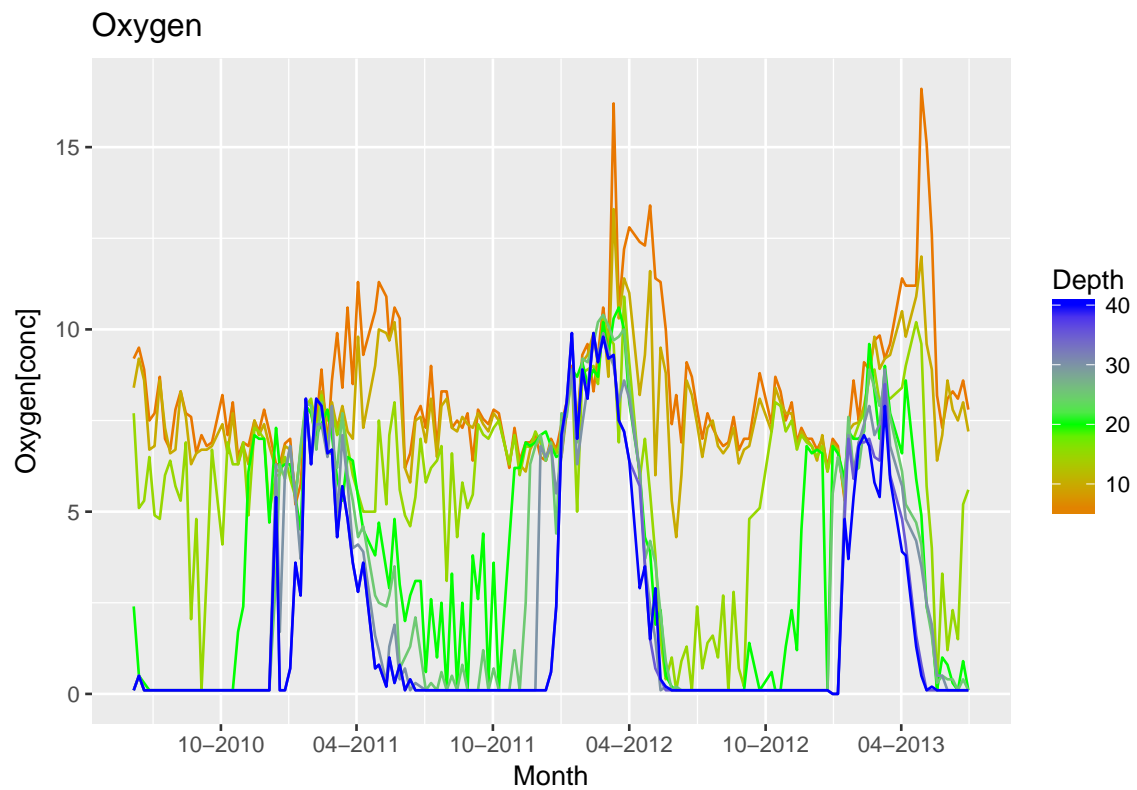
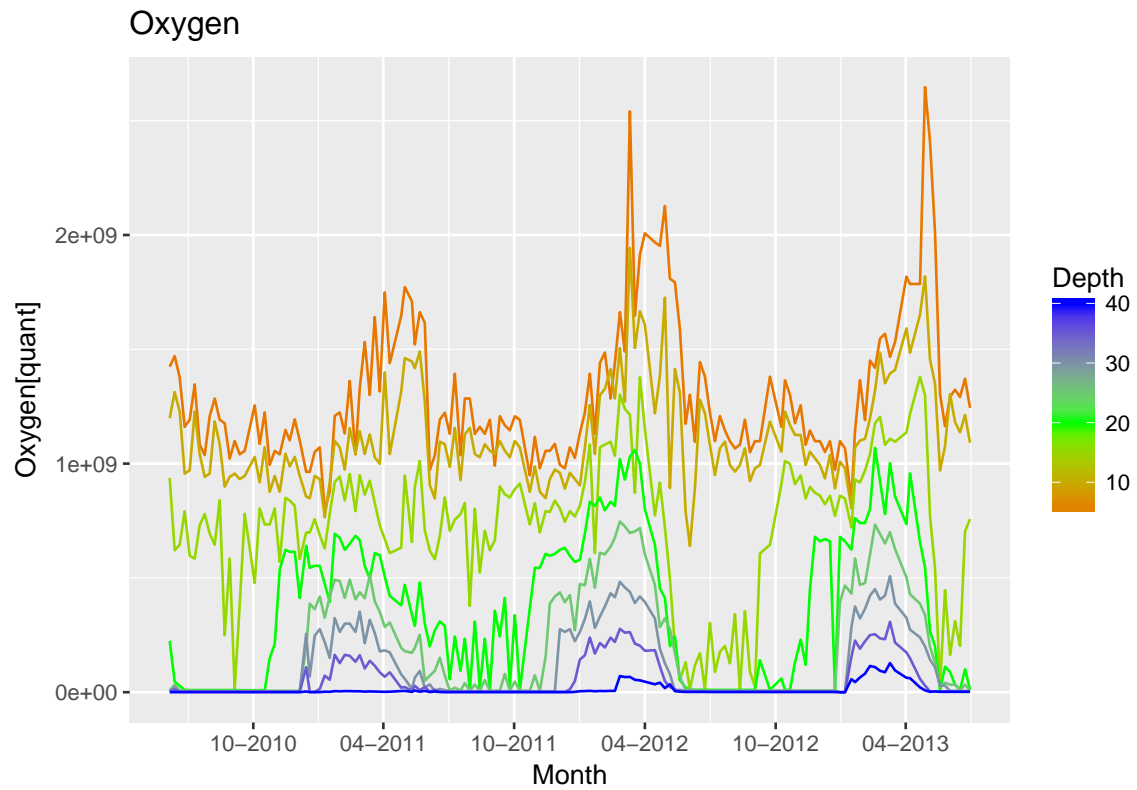
Oxygen [concentration]

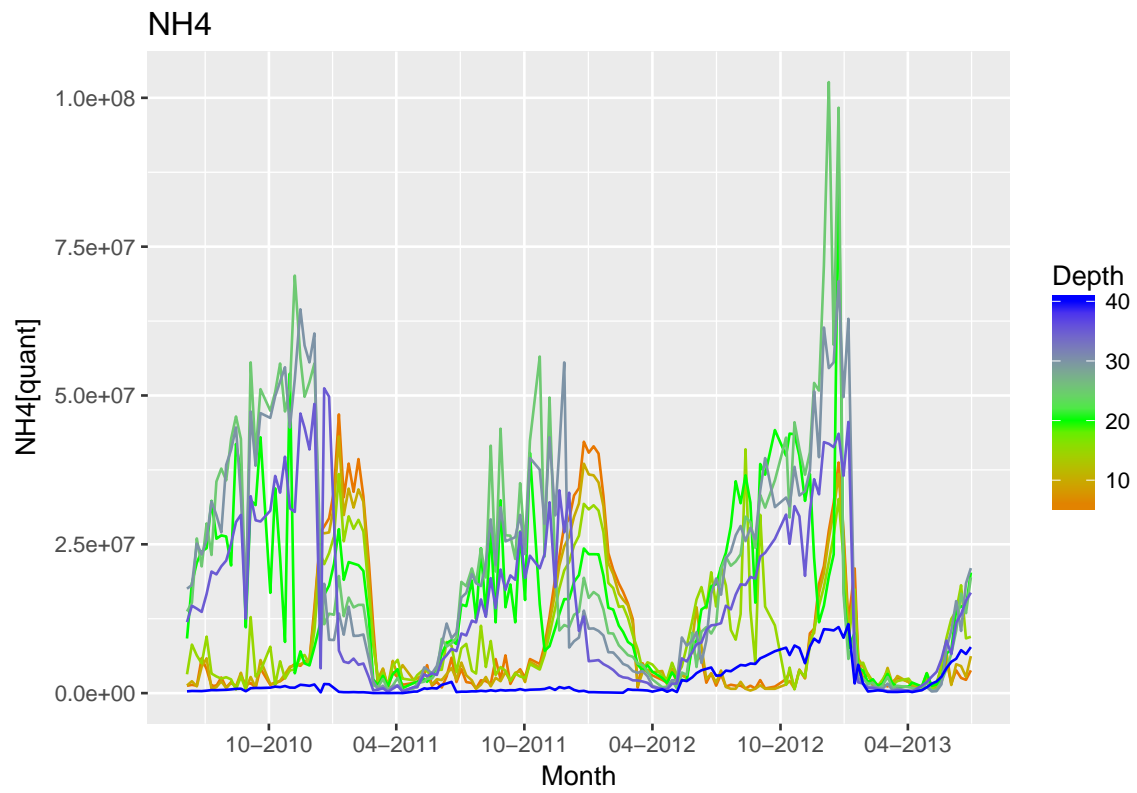
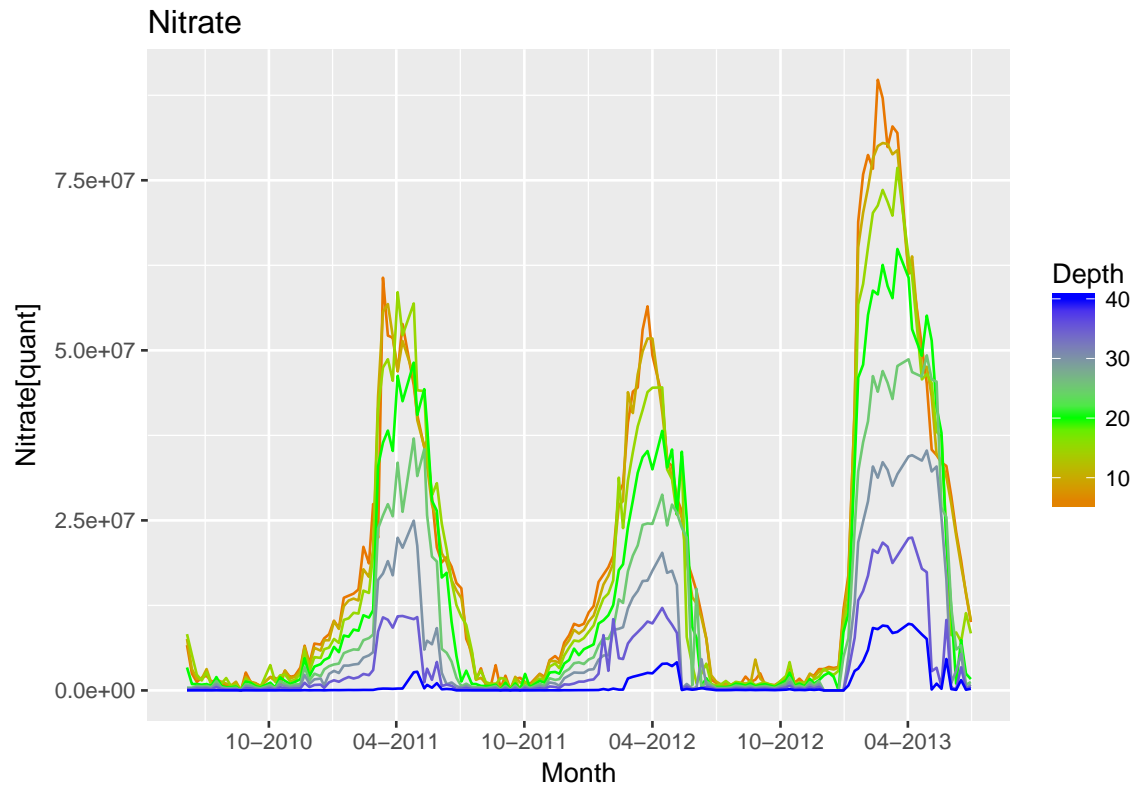






Time-depth cross sections

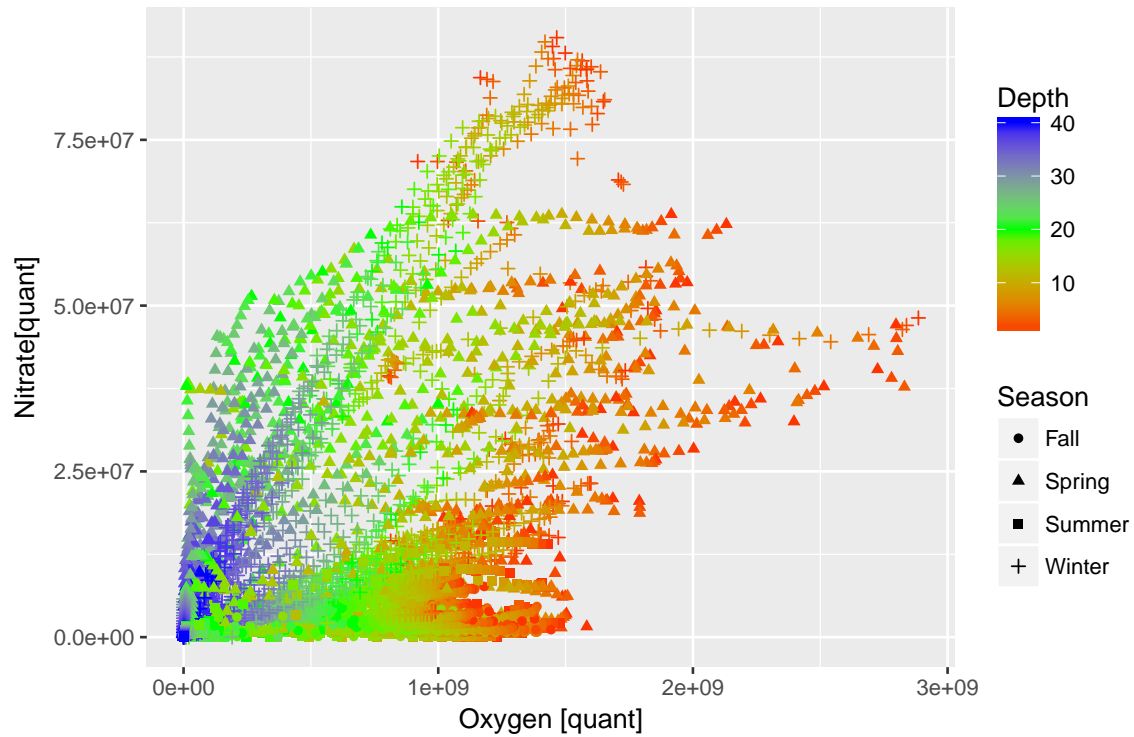




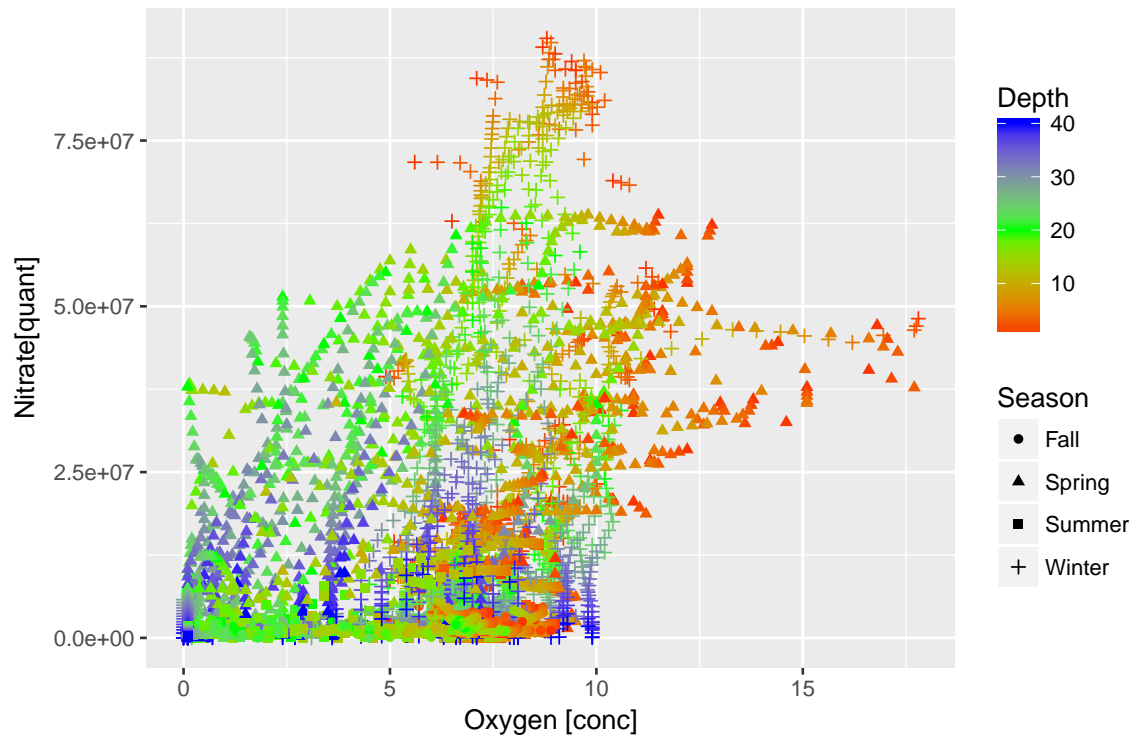
Correlation plots

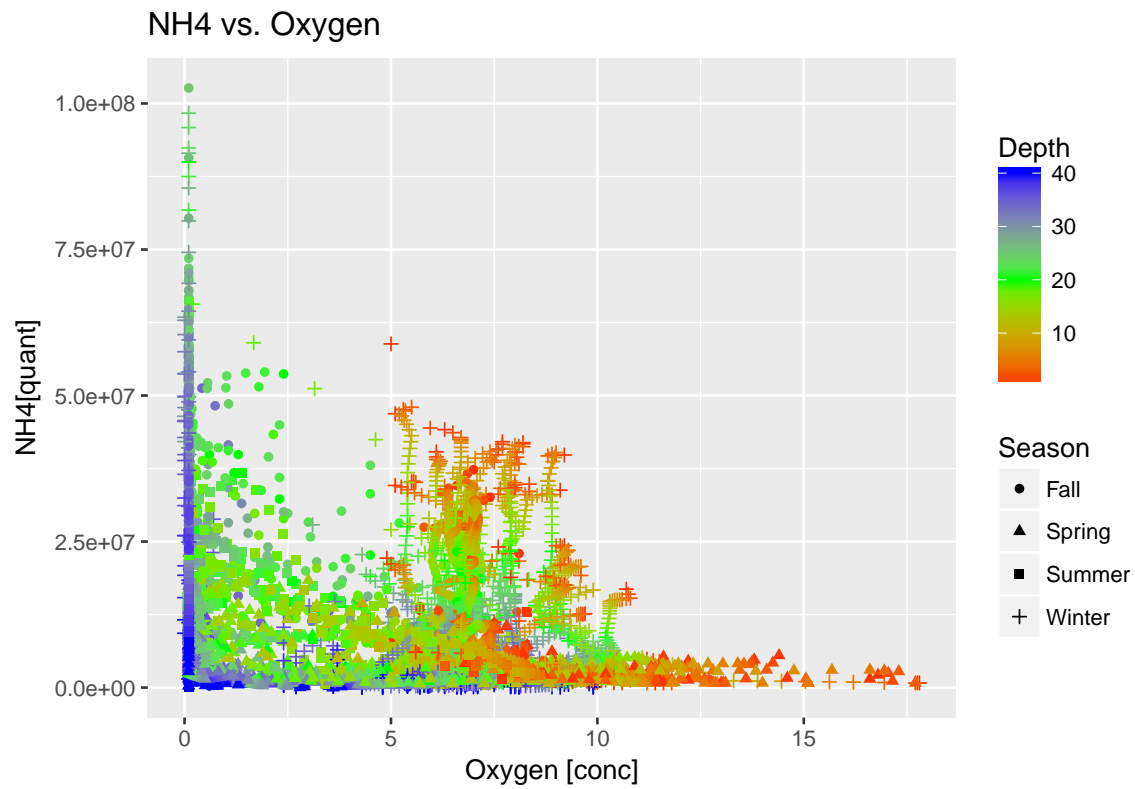
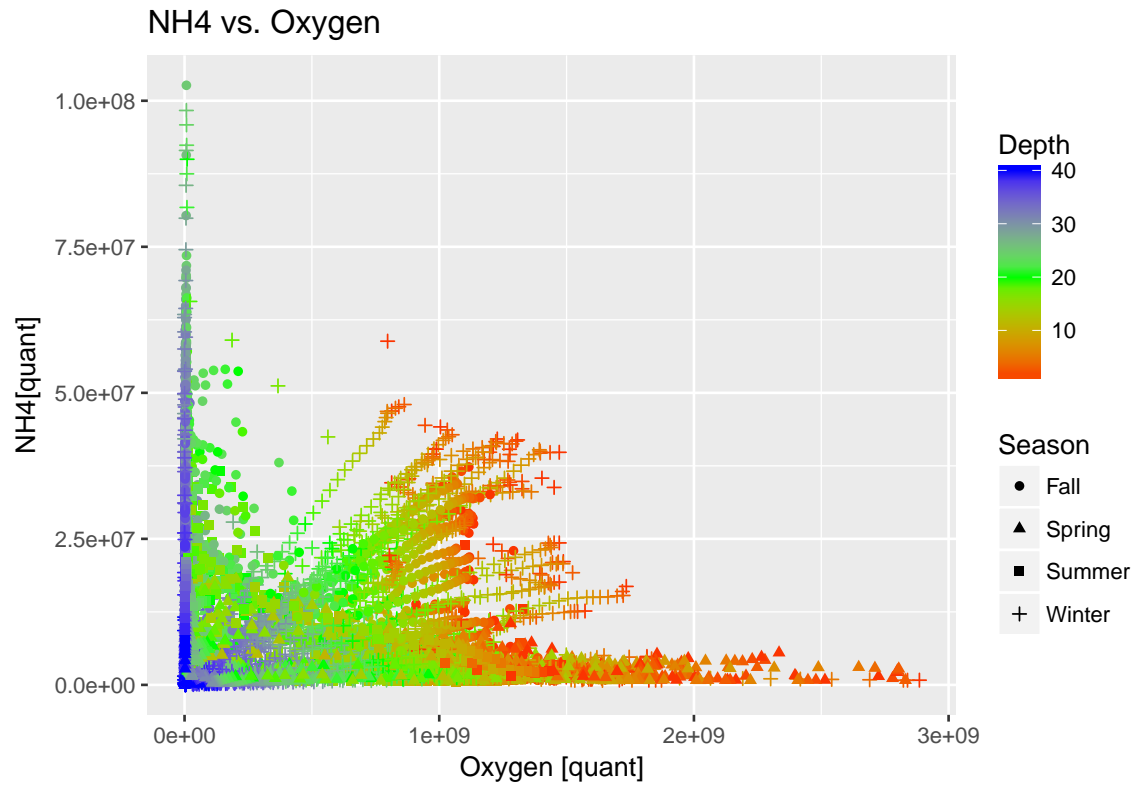
The following plots provide some visual estimation of data correlation

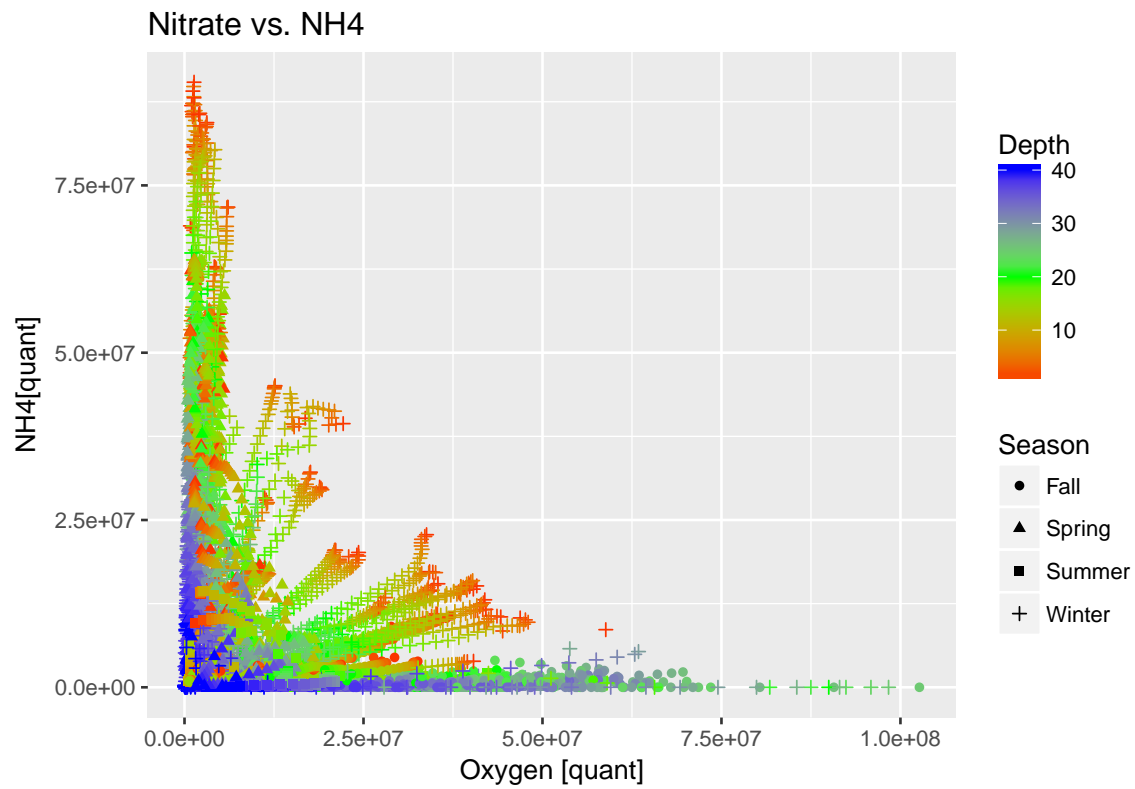
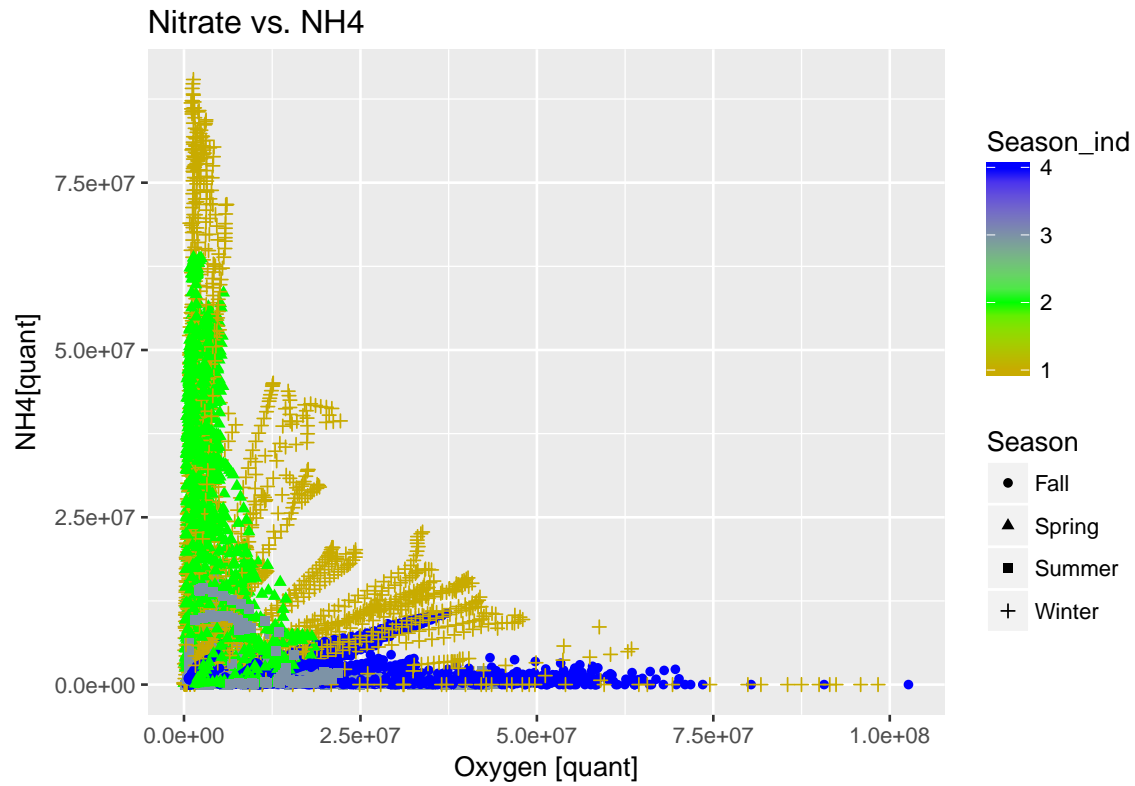
Nitrate vs. Oxygen



Nitrate vs. Oxygen

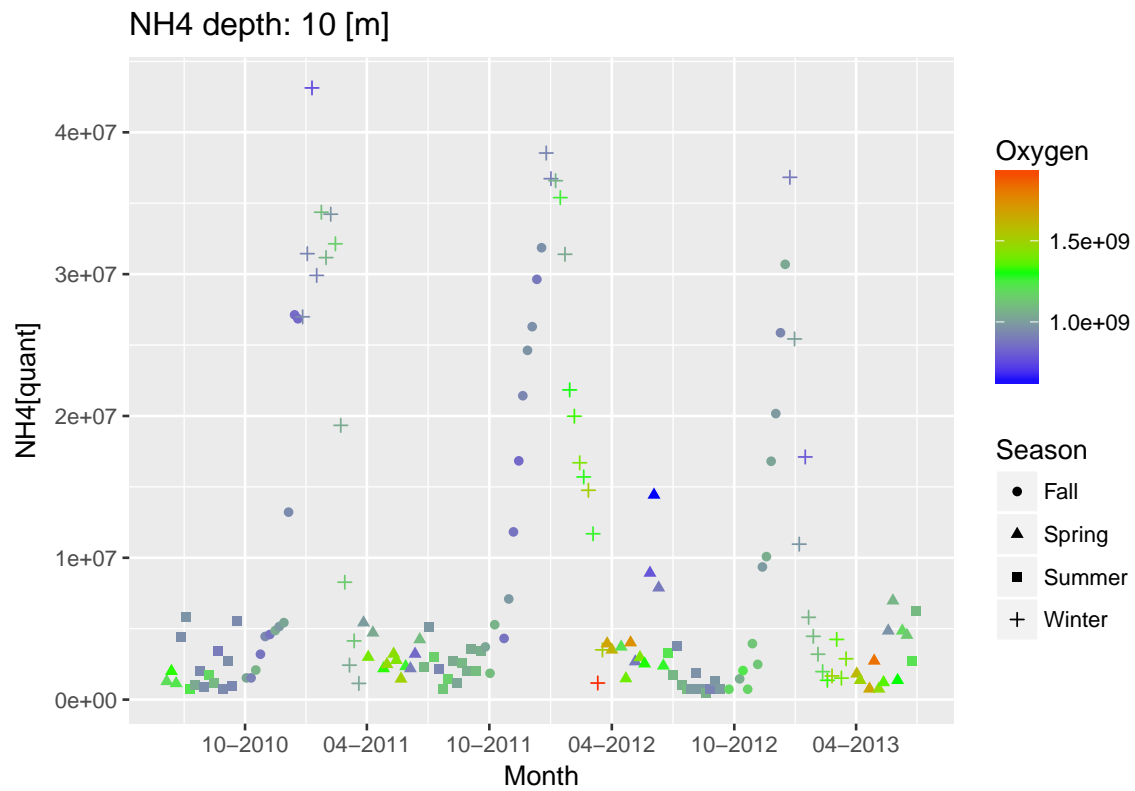
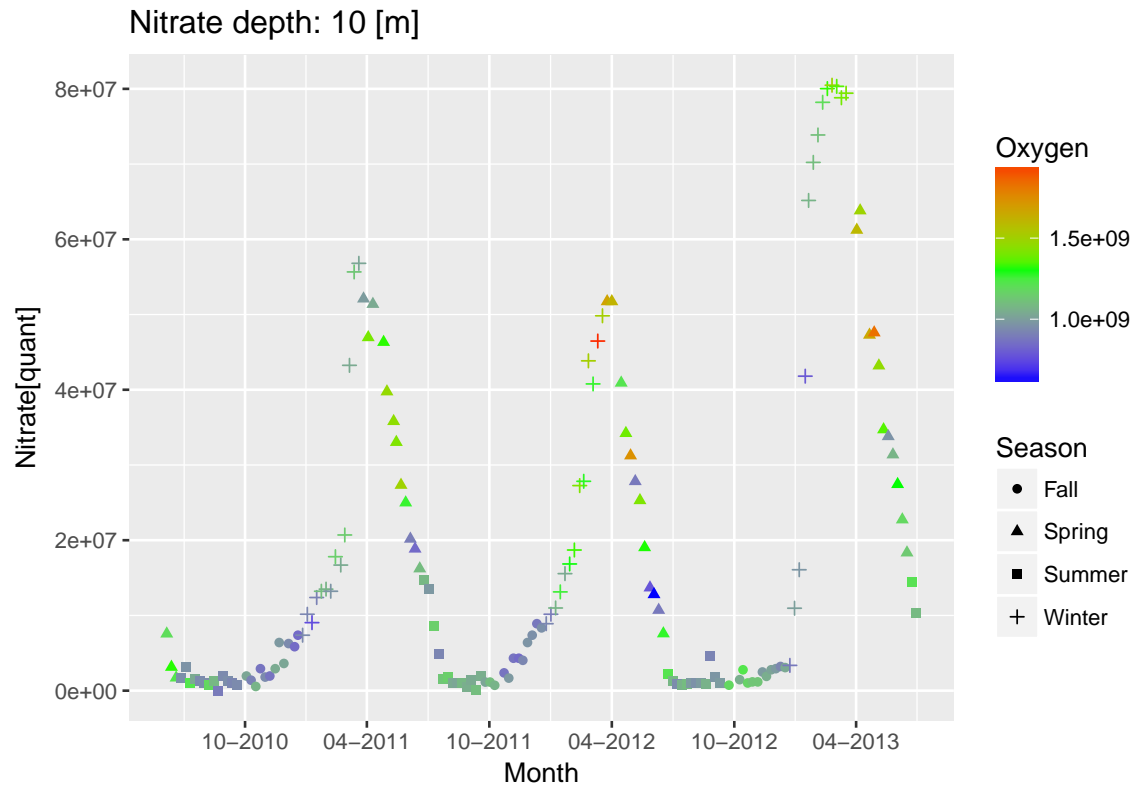


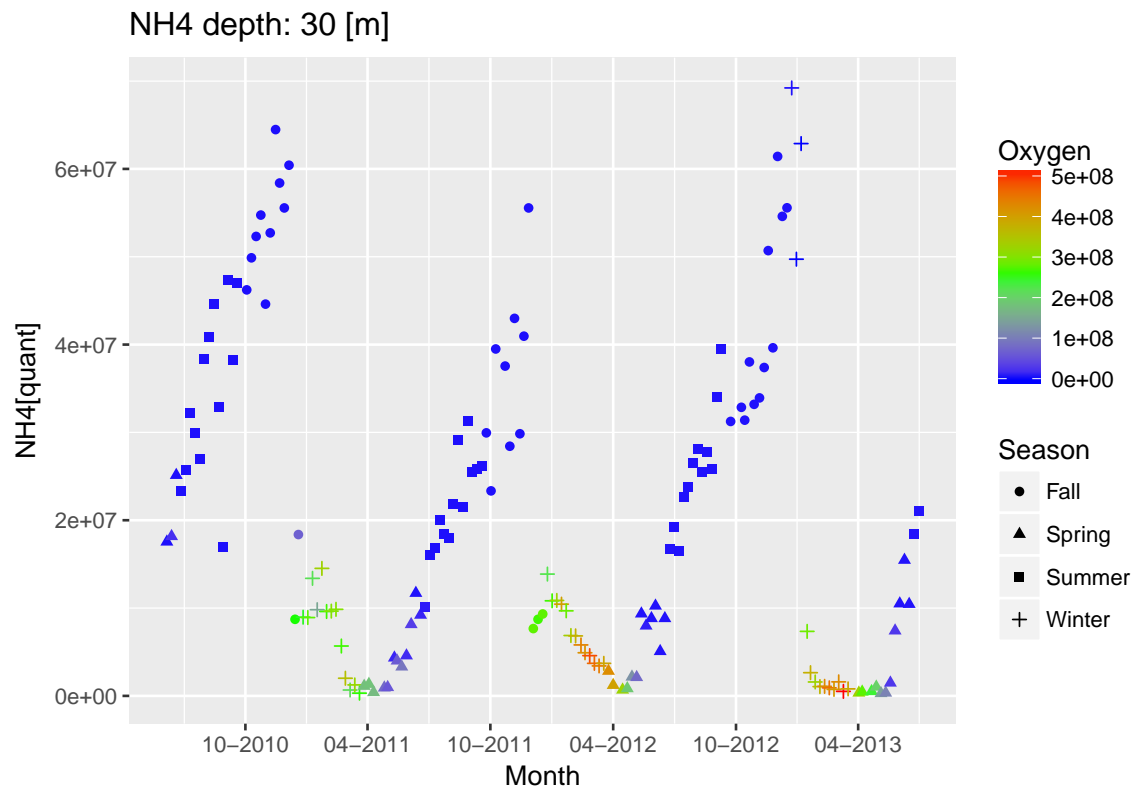
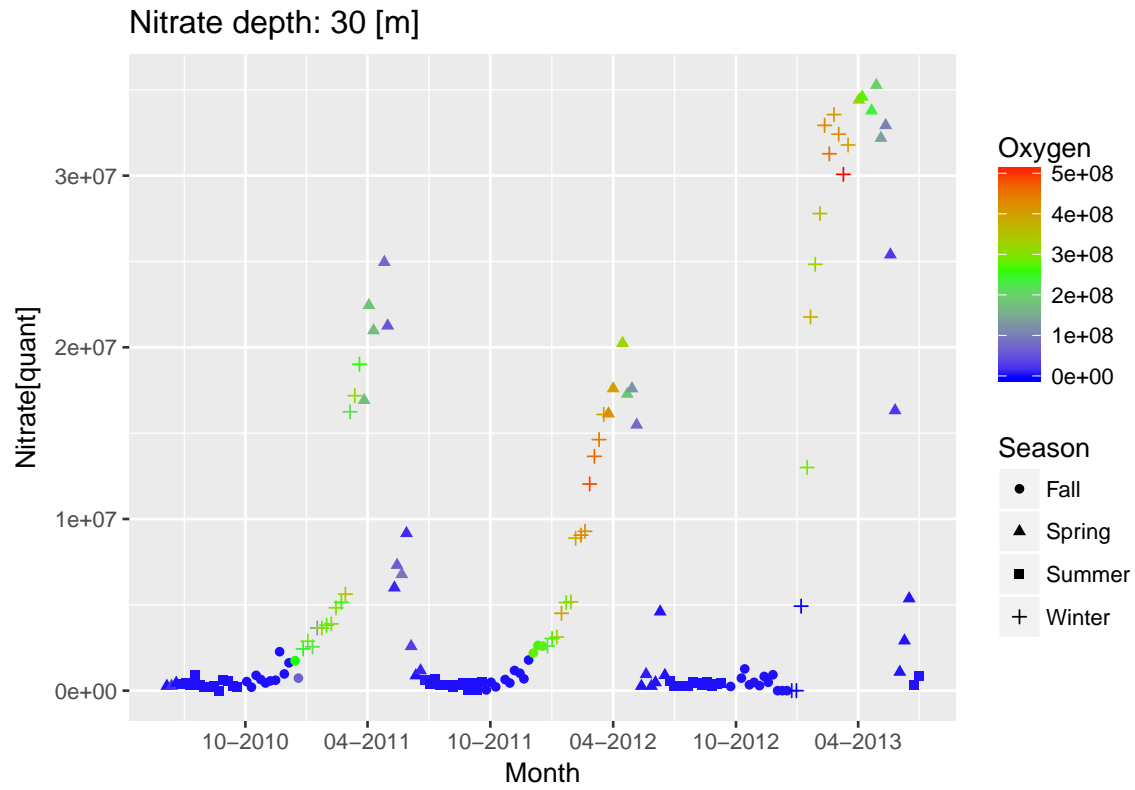




Model fitting estimation

Nitrification and denitrification are two opposing processes that take place in the presence or absence of oxygen. They therefore develop in the upper (nitrification) and lower (denitrification) parts of the lake during episodes of a stratified water column. The model therefore relies on the assumption that their development depends on the presence of oxygen and the time available for their accumulation. Lake mixing, which takes place during winter, disrupts their build-up, and uniformly distributes them across the lake, and mixing propagates towards the lake bottom. These two processes (stratification and mixing) can be examined in detail in two representative depths of 10m (nitrification) and 30m (denitrification).

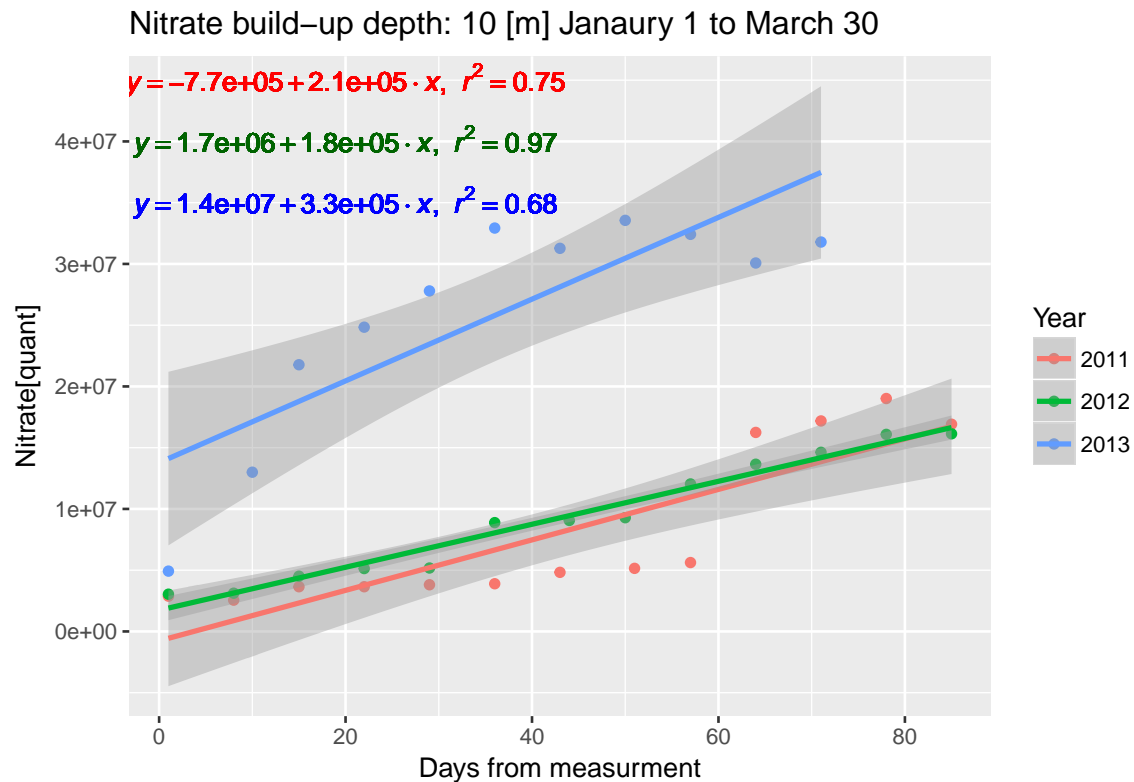




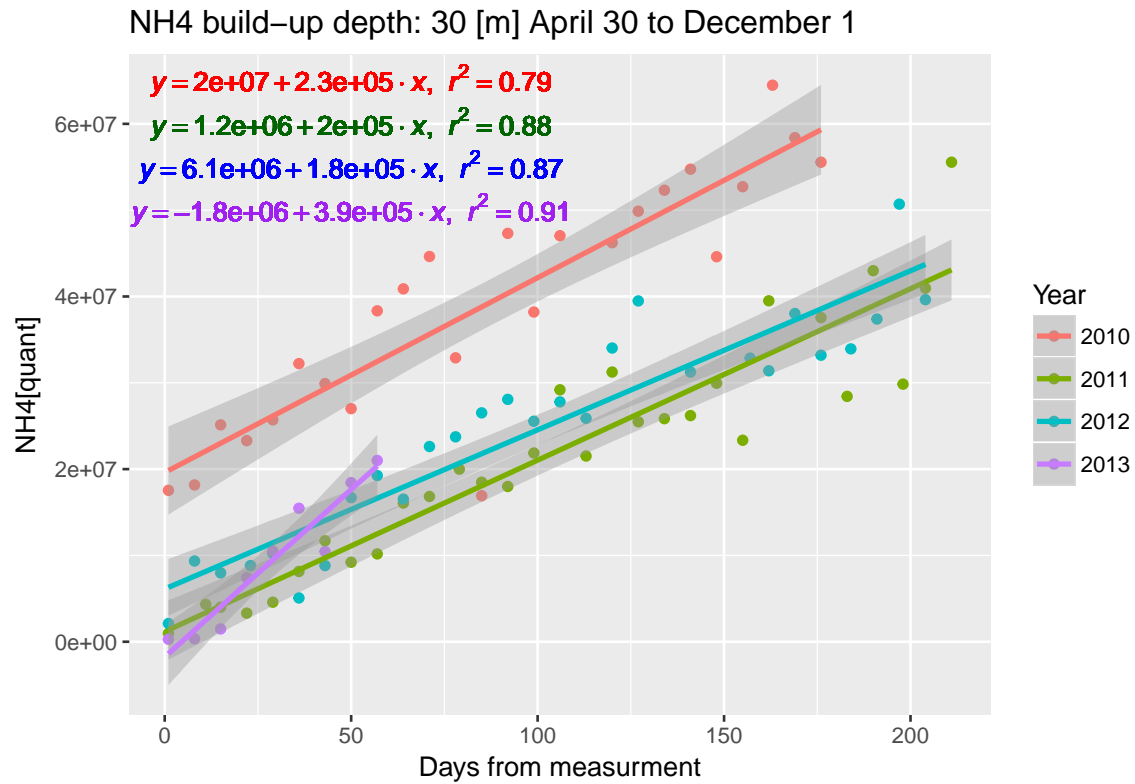
Process rate estimation

It can be observed from the figures presented above that nitrification is dominant in the upper portions of the lake (depicted for 10m depth), primarily between January and April, when the mixing of the lake decreases its content through a down-ward propagating mixing of the oxygenated epilimnion with the lower, oxygen-depleted hypolimnion. Ammonium, on the other hand, develops during the stratified lake conditions in its hypolimnion (depicted for depth 30 m), and peaks at the beginning of May, right before the mixing of the lake reaches the deeper parts of the lake, denitrification is halted, and the deeper lake is oxygenated once more.

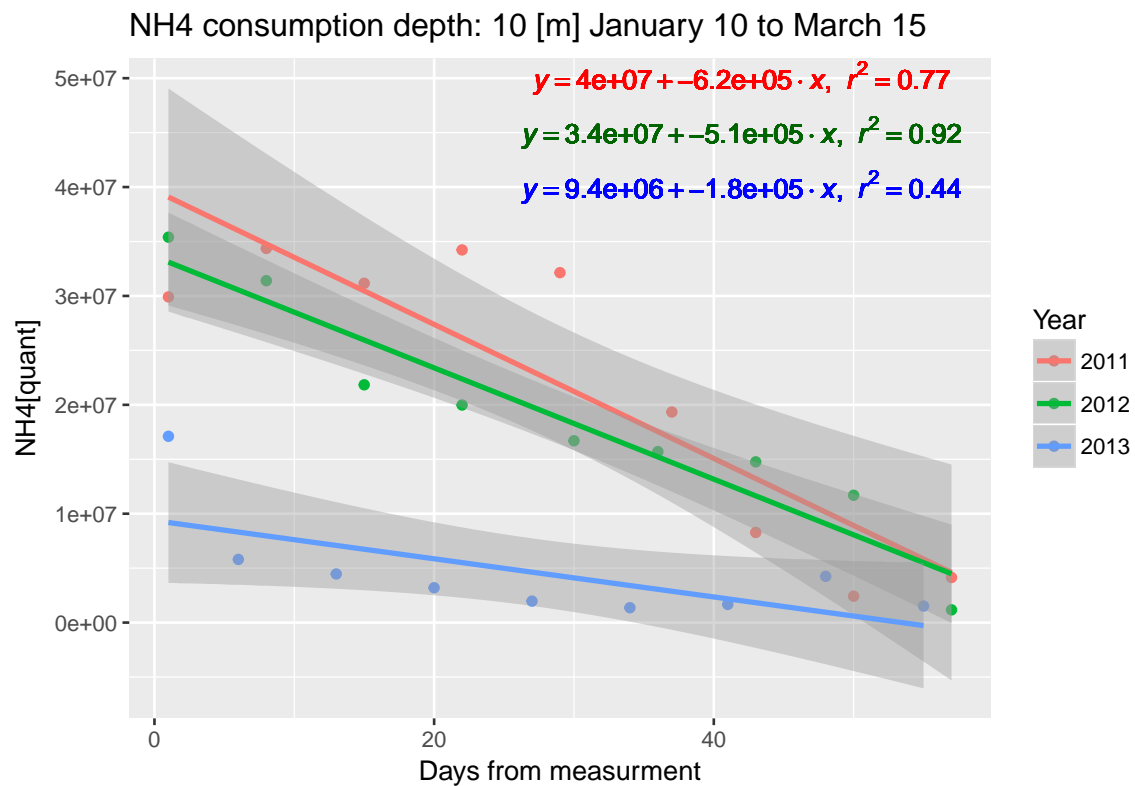
Simulate Nitrate build-up between November 1st and April 30st in 10m depth in order to estimate processes rate



simulate NH4 build-up between April 30st and December 1st in 30m depth in order to estimate reaction rate



simulate NH4 consumption between January 10th and March 15th in 30m depth in order to estimate reaction rate



Coefficients assesment for all depths

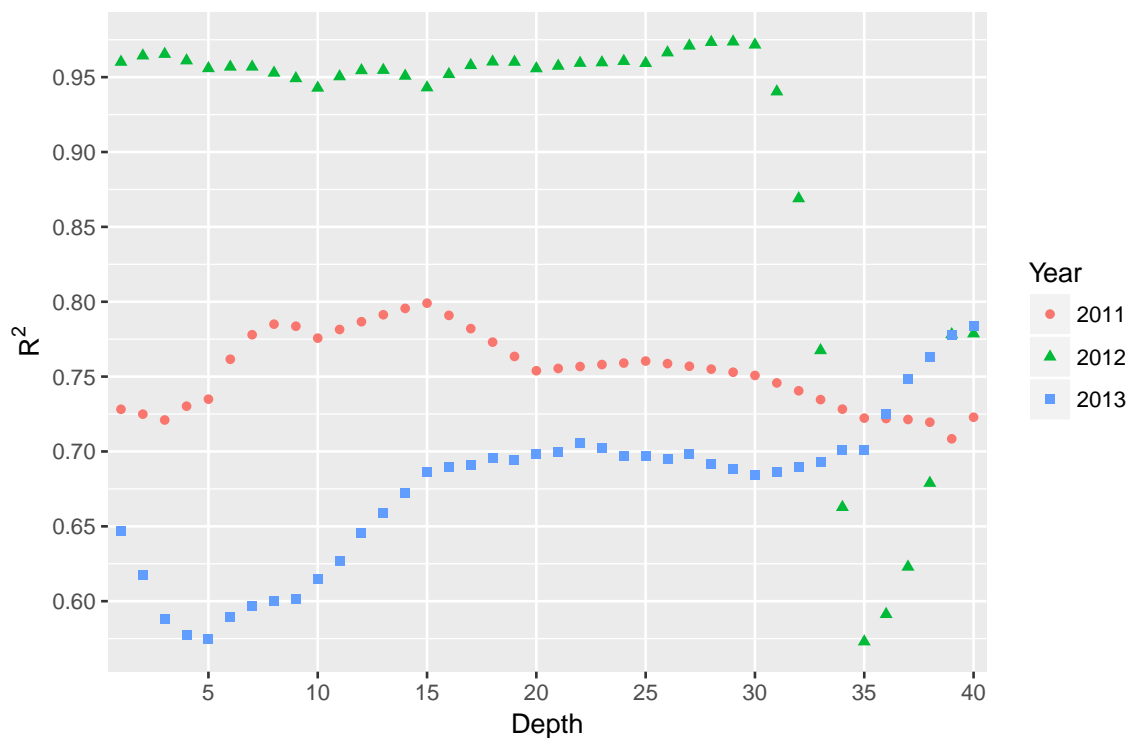
After consideration of the dominant processes that control nitrate and ammonium content in the lake, the following section provides an assesment of the processes and their fit to a linear model in each depth. The R^2 value can be used to asses the best fit of the model for each depth. It can be observed that nitrate buildup fits a linear model in most depths, although some intraannual changes illustrate the complexity of the system and its divergence from linearity. The coefficients of the model also show a wide range, and illustrate that the best R^2 values were found for the year 2012 (triangles) and values of ca. $a = 5 * 10^6$ and $b = 4 * 10^5$ that describe nitrate build up between Novemebr 1st and April 31st using the following equation:

$$NO_3 = 5 * 10^6 * t + 4 * 10^5$$

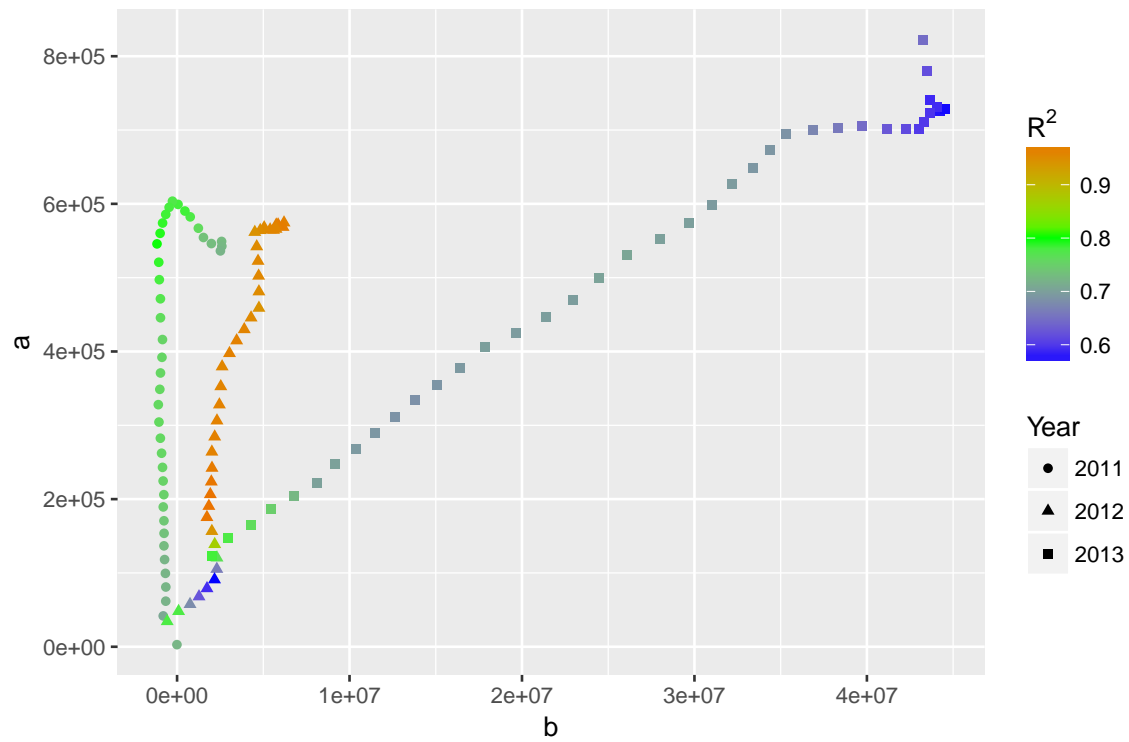
, where t is provided in days.

##	Depth	a	b	r2
##	Min. : 1.00	Min. : 2837	Min. : -1163352	Min. : 0.5730
##	1st Qu.: 10.75	1st Qu.: 223195	1st Qu.: -315929	1st Qu.: 0.6953
##	Median : 20.50	Median : 437797	Median : 2589163	Median : 0.7545
##	Mean : 20.50	Mean : 409771	Mean : 9884307	Mean : 0.7765
##	3rd Qu.: 30.25	3rd Qu.: 569284	3rd Qu.: 12924573	3rd Qu.: 0.9409
##	Max. : 40.00	Max. : 822536	Max. : 44544584	Max. : 0.9737

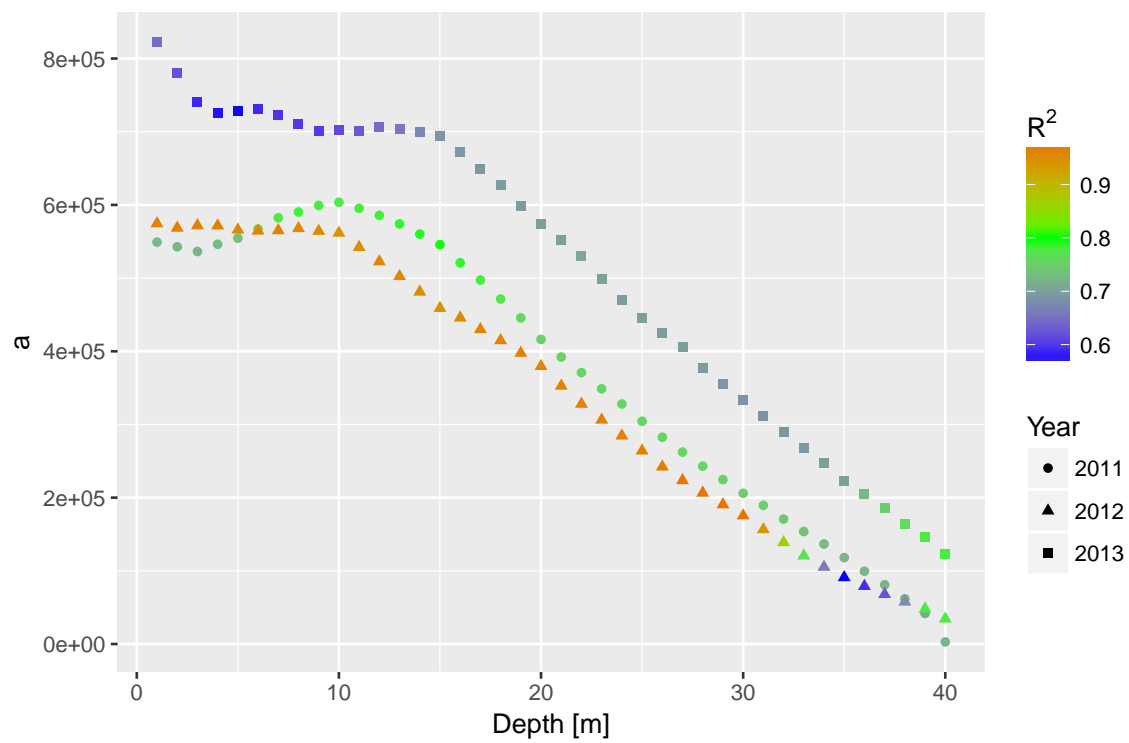
Nitrate build-up Linear Modeling: Janaury 1 to March 30



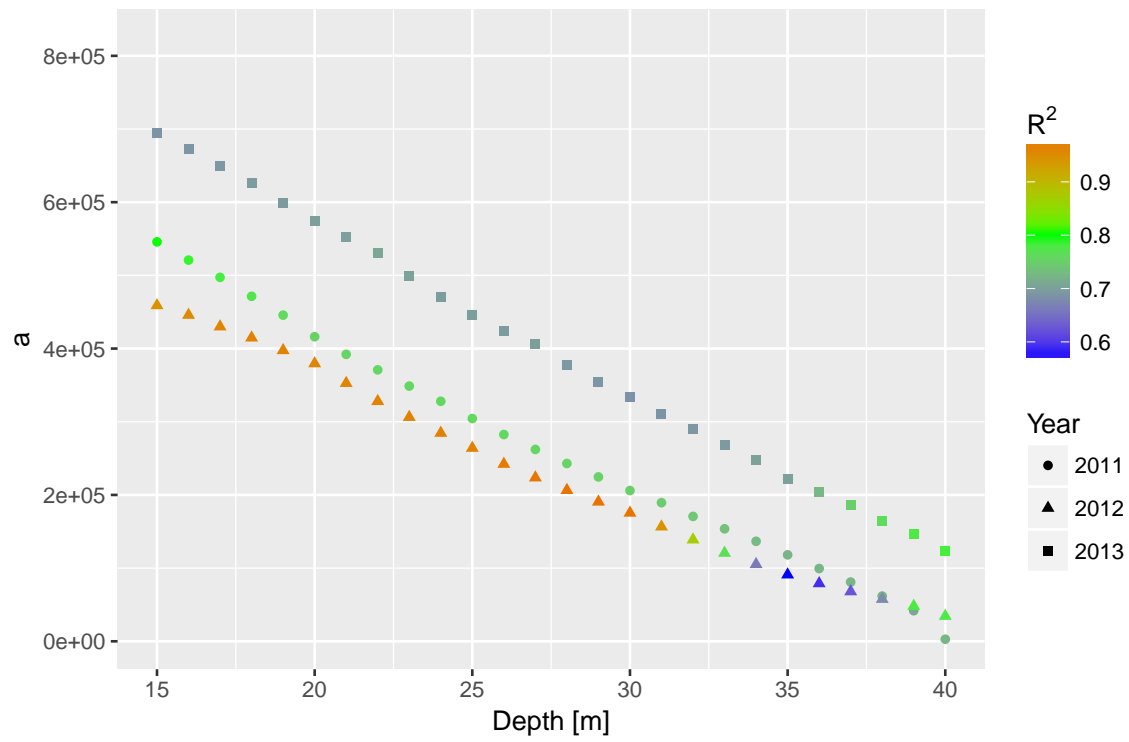
Nitrate build-up Linear Modeling: Janaury 1 to March 30



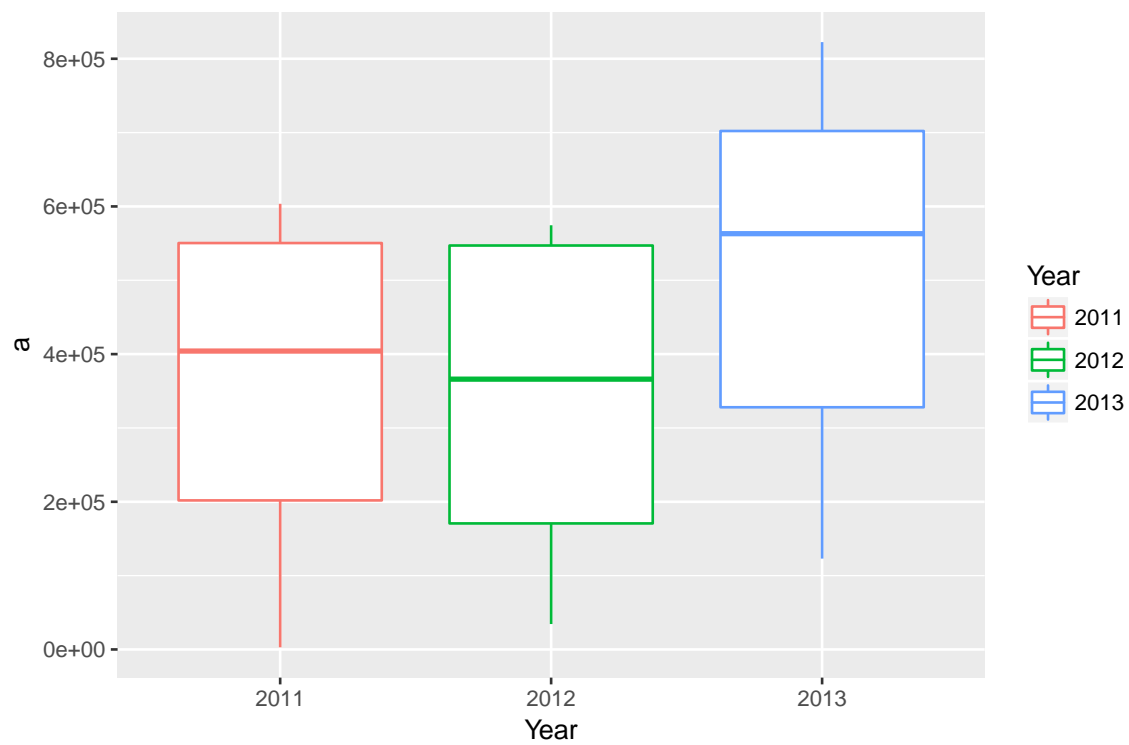
Nitrate build-up Linear Modeling: Janaury 1 to March 30



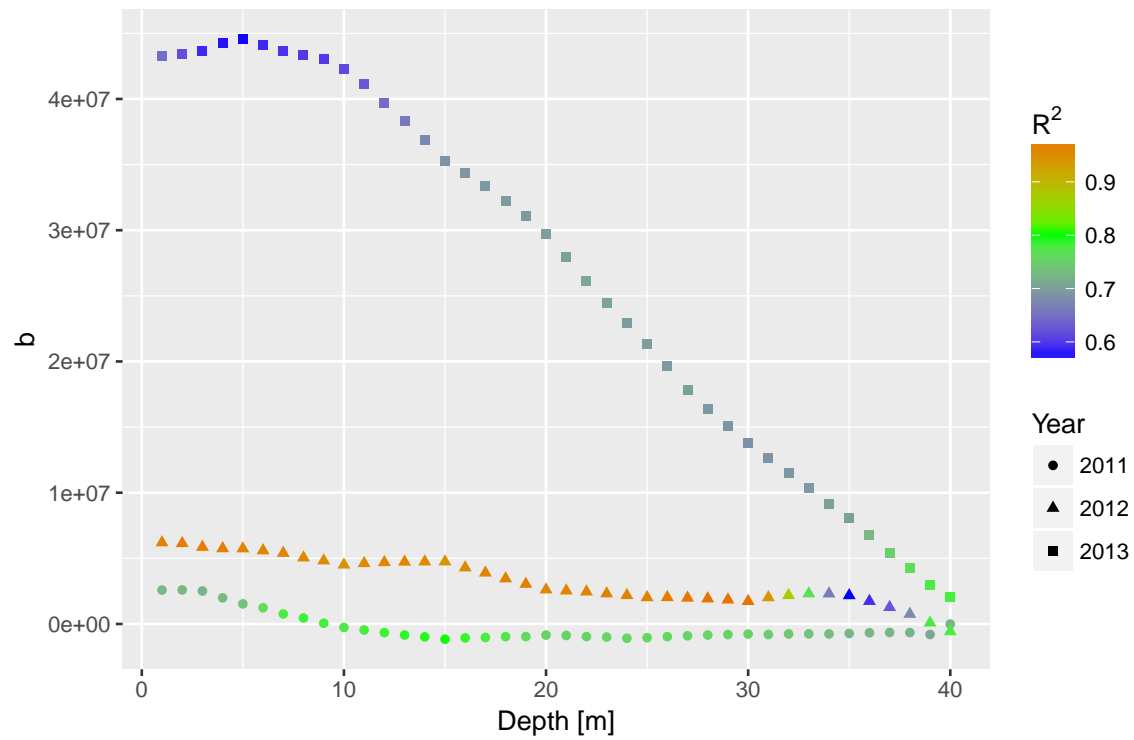
Nitrate build-up Linear Modeling: Janaury 1 to March 30



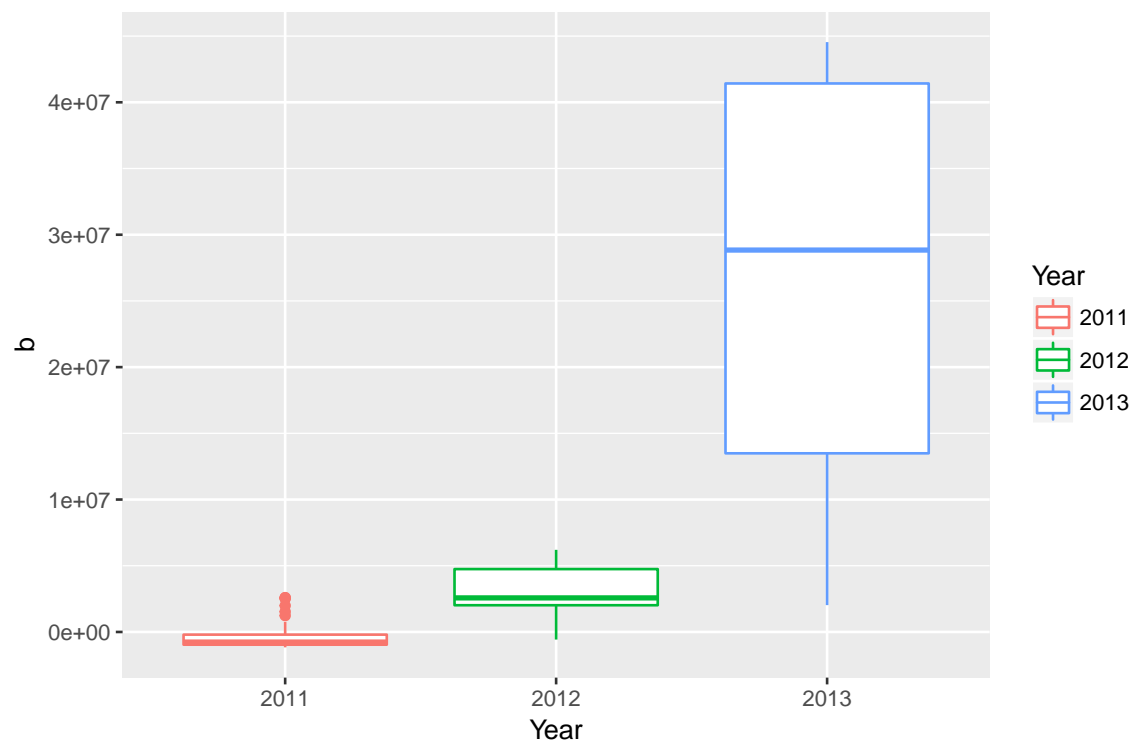
a parameter for Nitrate build-up: Janaury 1 to March 30

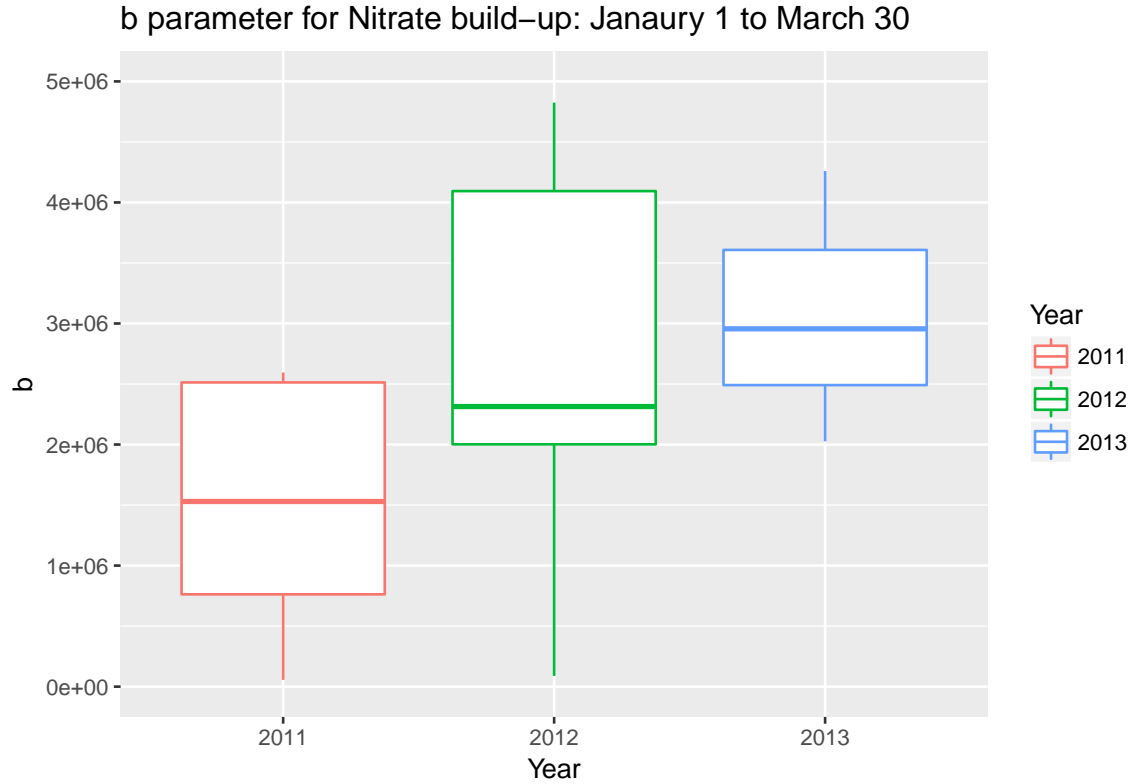


Nitrate build-up Linear Modeling: Janaury 1 to March 30



b parameter for Nitrate build-up: Janaury 1 to March 30





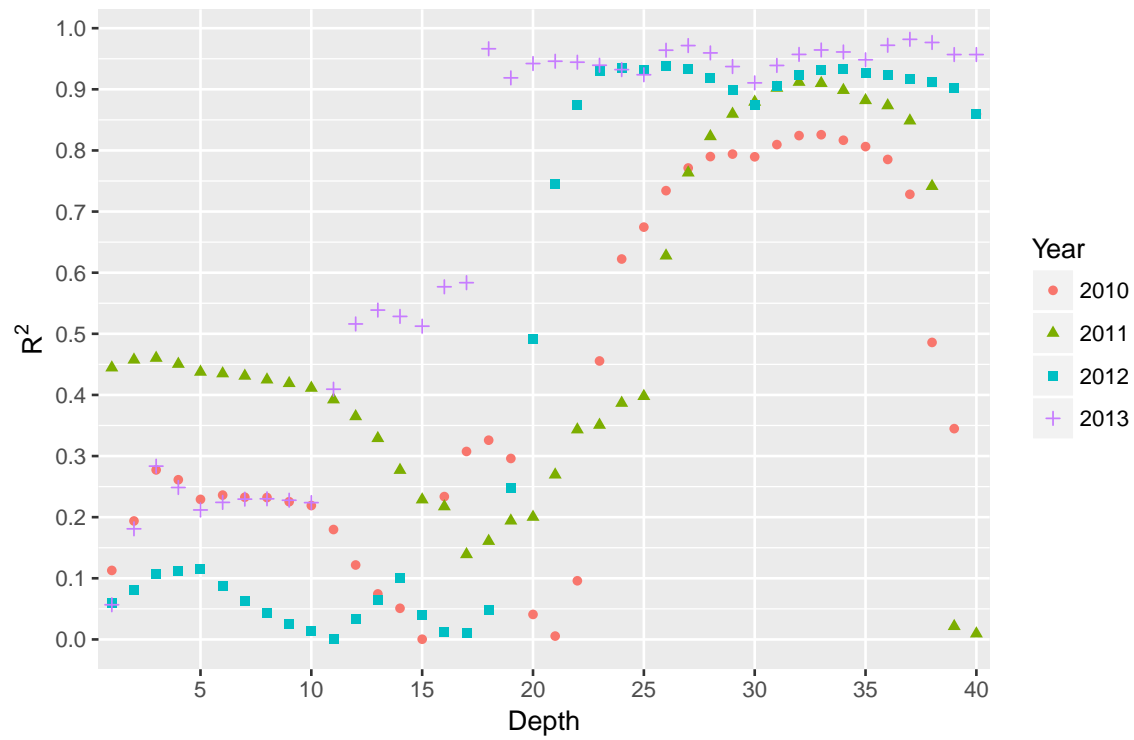
It can be observed that ammonium buildup does fit the linear model in most depths as nicely as nitrate. Intraannual changes are significant, and once more illustrate the complexity of the system and its divergence from linearity. The coefficients of the model show a slightly smaller range, and illustrate that the best R^2 values of ca. $a = 5 * 10^6$ and $b = 5 * 10^5$ that describe ammonium build up between April 30th and December 1st using the following equation:

$$NH_4 = 5 * 10^6 t + 5 * 10^5$$

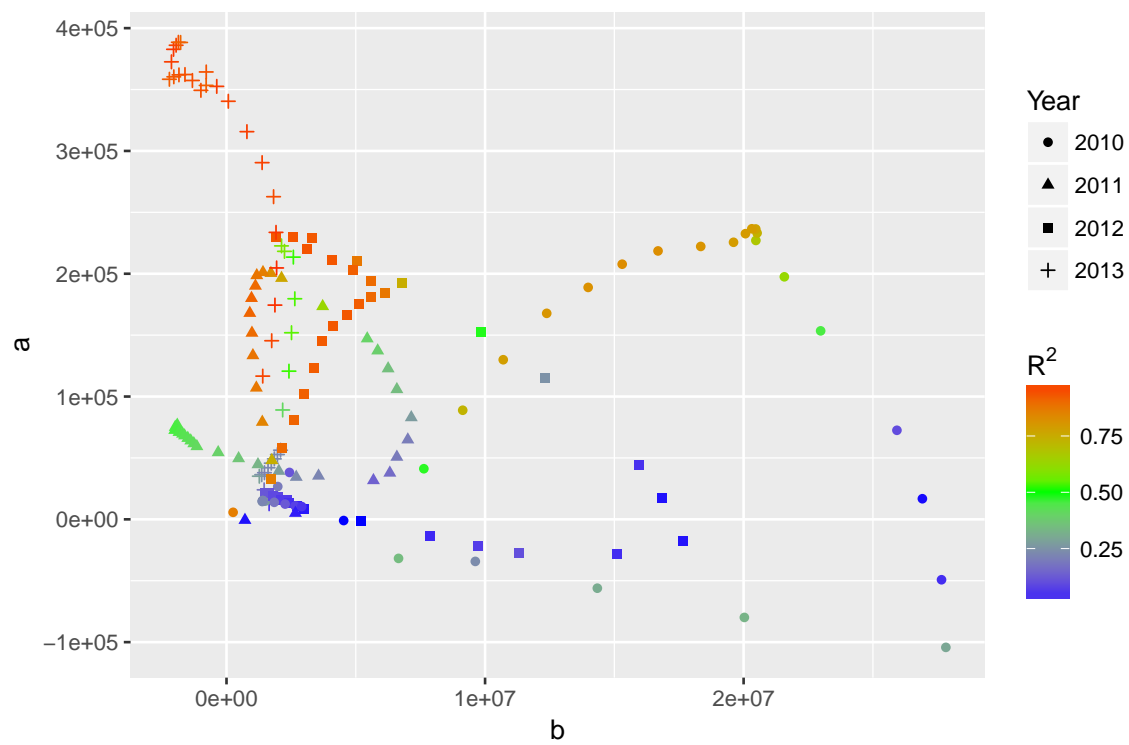
, where t is provided in days. Unsurprisingly, the model has the best fit for depths of 20 to 35m, where oxygenation is solely depends on annual stratification and monomictic mixing.

##	Depth	a	b	r2
##	Min. : 1.00	Min. : -104262	Min. : -2209182	Min. : 0.0003153
##	1st Qu.: 10.75	1st Qu.: 21419	1st Qu.: 1373549	1st Qu.: 0.2240937
##	Median : 20.50	Median : 81791	Median : 2140742	Median : 0.4588809
##	Mean : 20.50	Mean : 120362	Mean : 4868893	Mean : 0.5247795
##	3rd Qu.: 30.25	3rd Qu.: 200613	3rd Qu.: 6149996	3rd Qu.: 0.9020609
##	Max. : 40.00	Max. : 388468	Max. : 27822019	Max. : 0.9818000

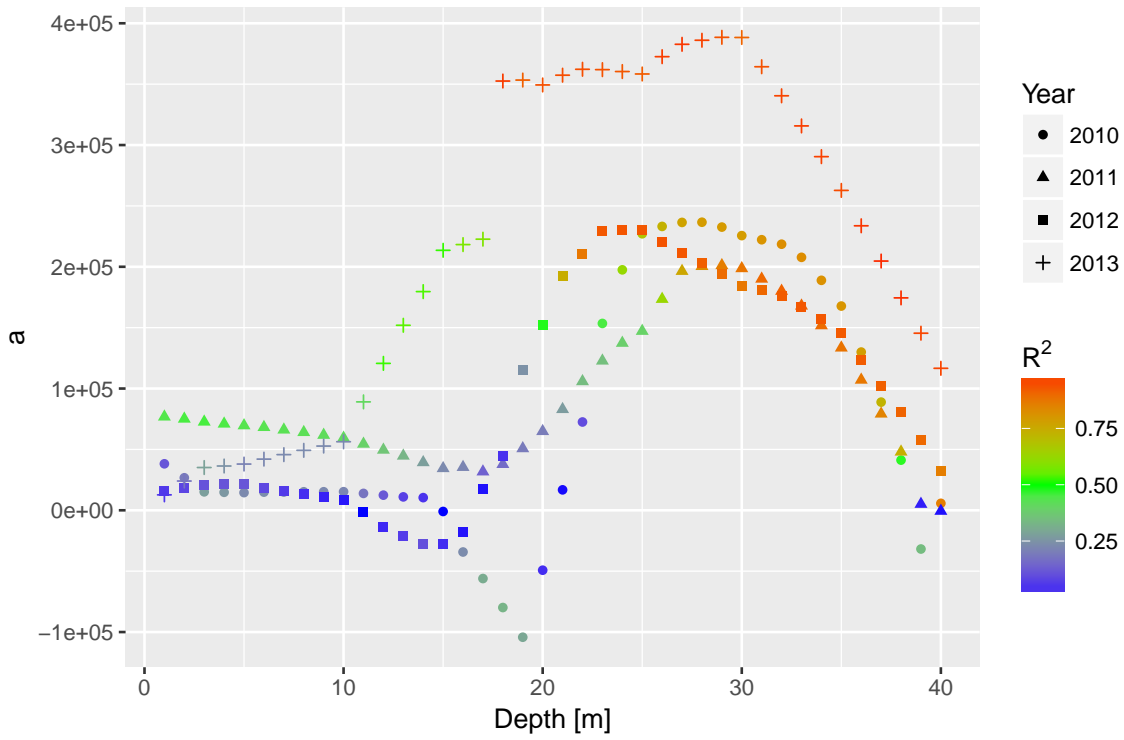
NH4 build-up Linear Modeling: April 30 to December 1



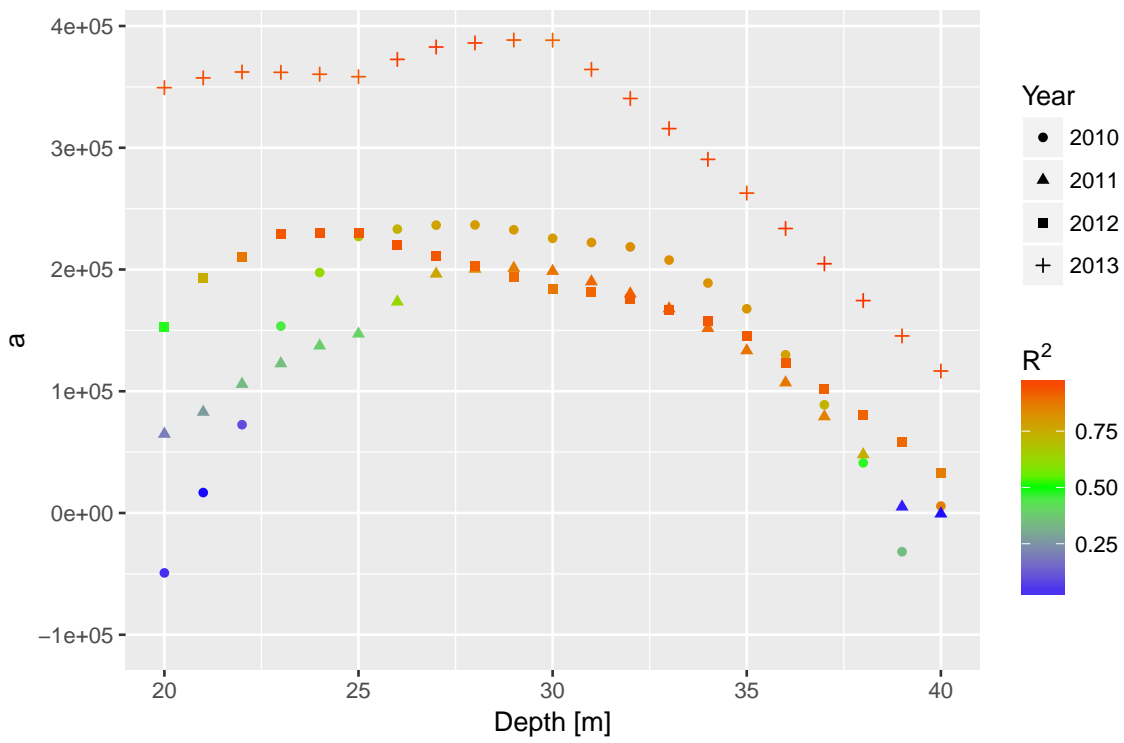
NH4 build-up Linear Modeling: April 30 to December 1

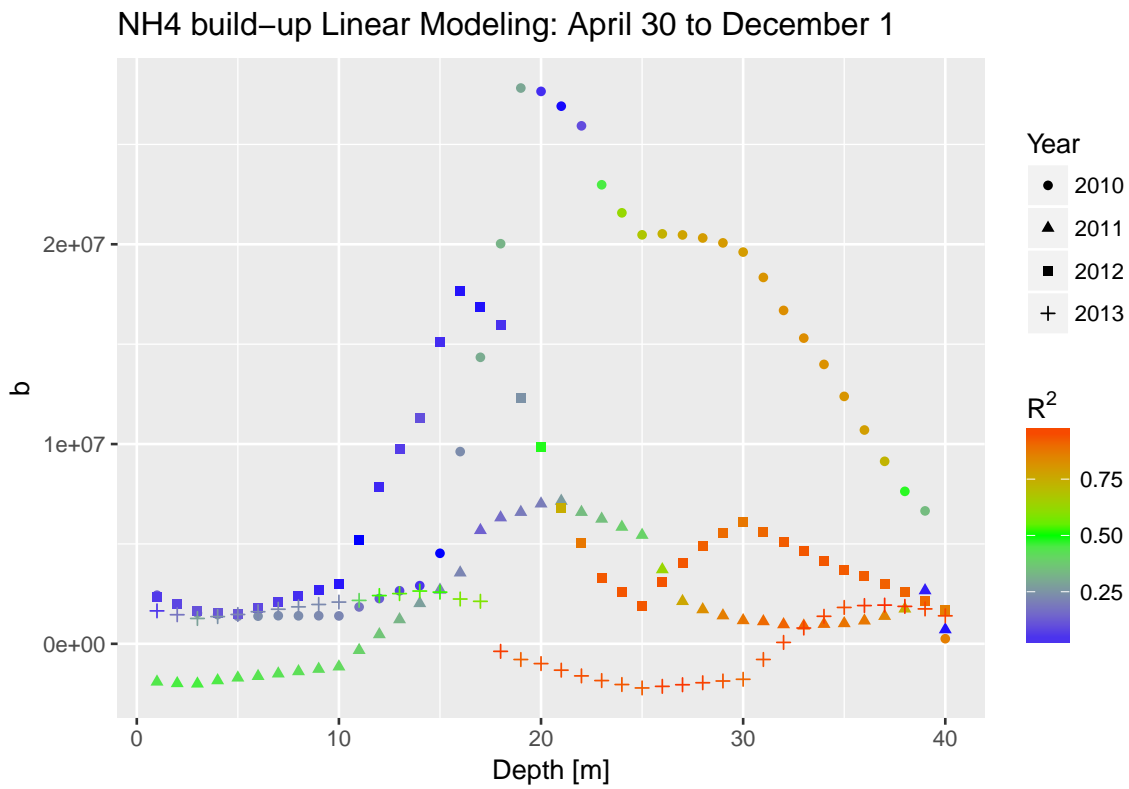
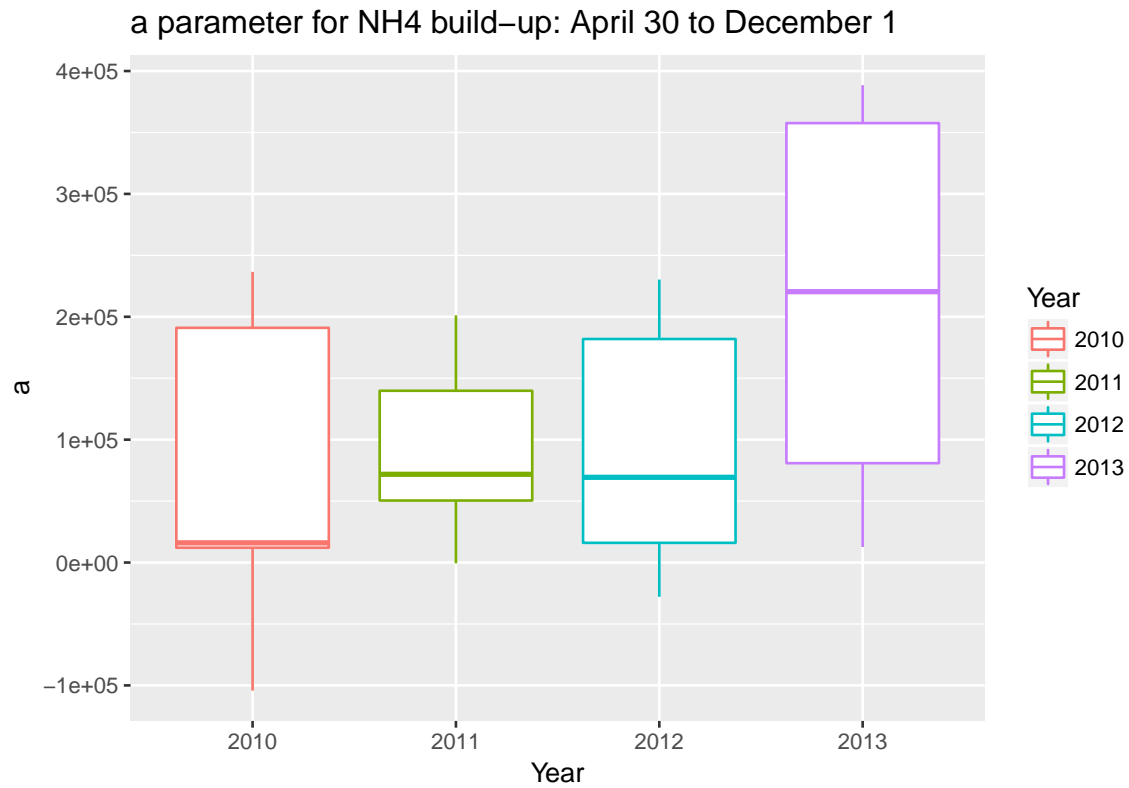


NH4 build-up Linear Modeling: April 30 to December 1

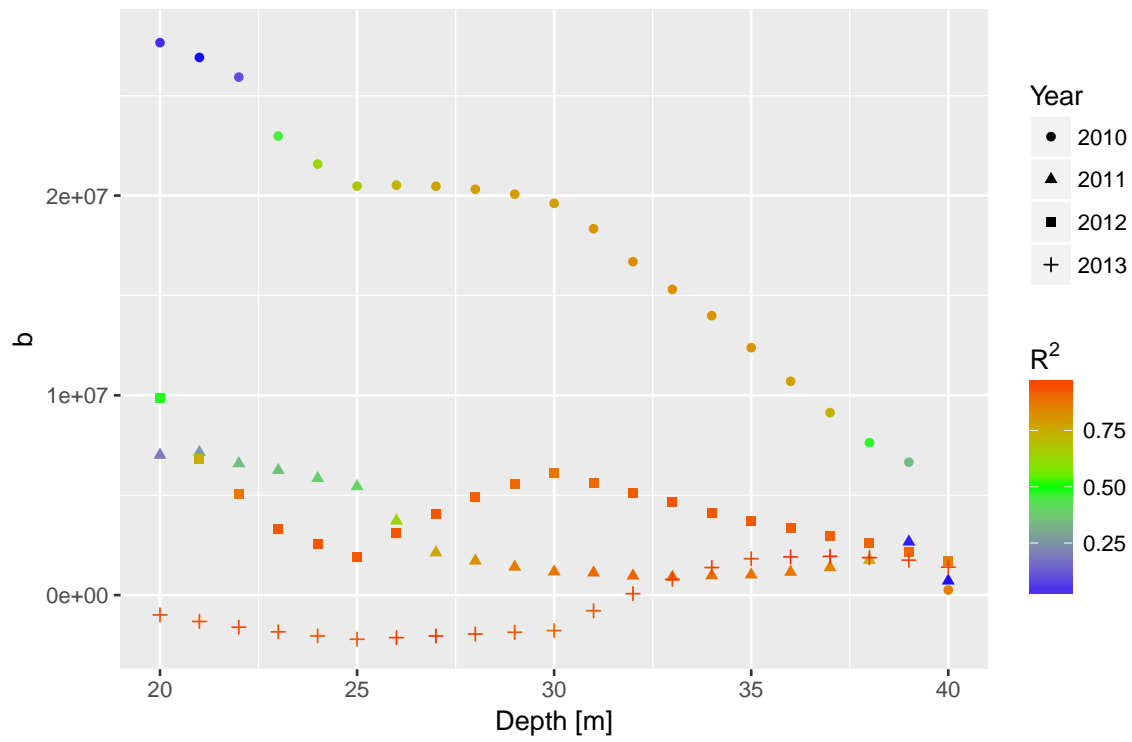


NH4 build-up Linear Modeling: April 30 to December 1

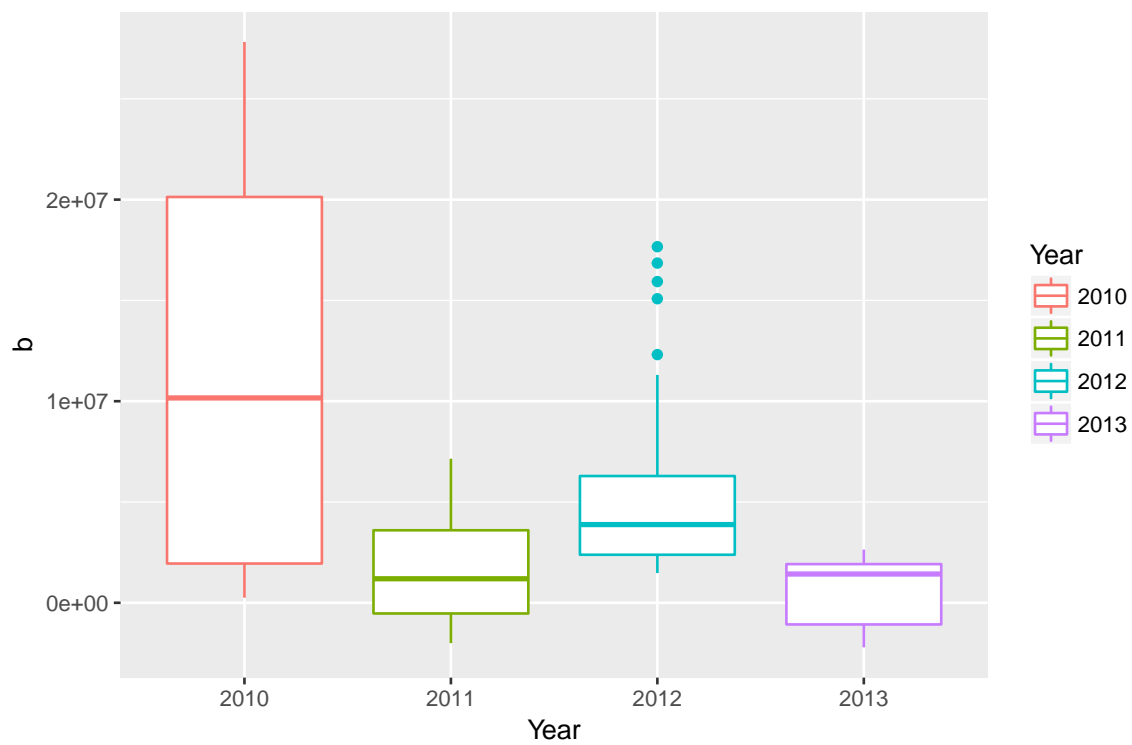


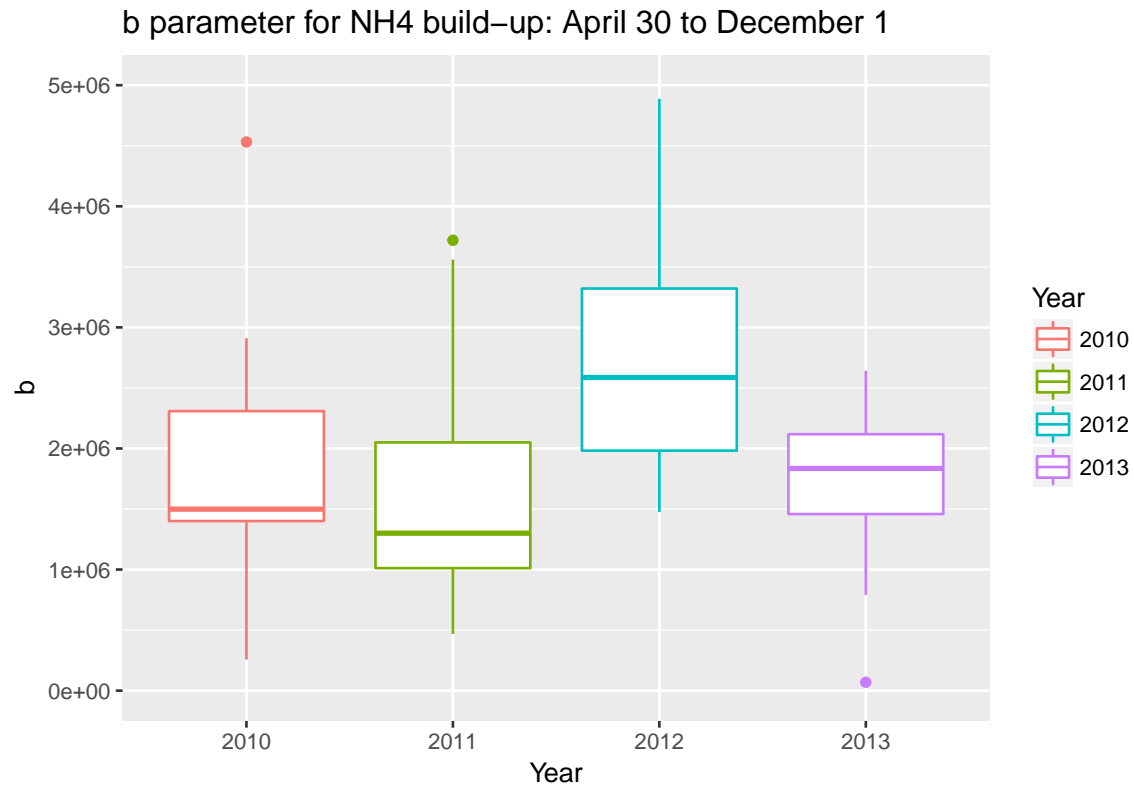


NH4 build-up Linear Modeling: April 30 to December 1



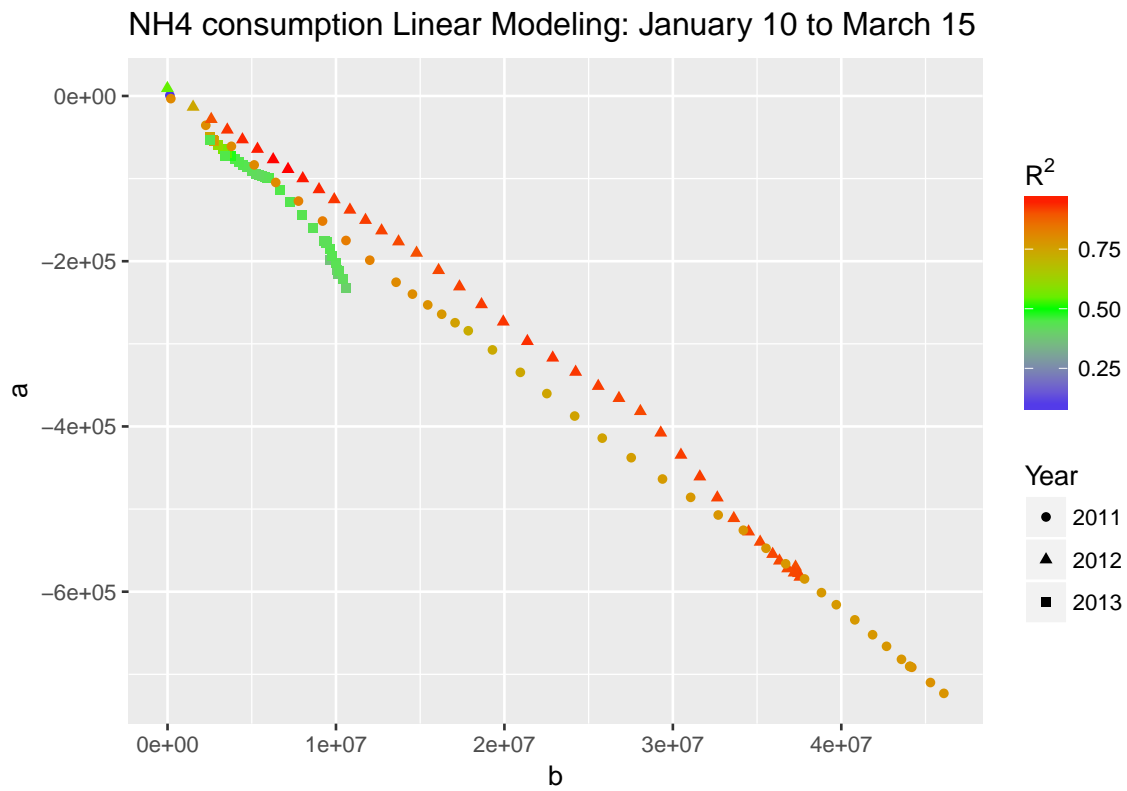
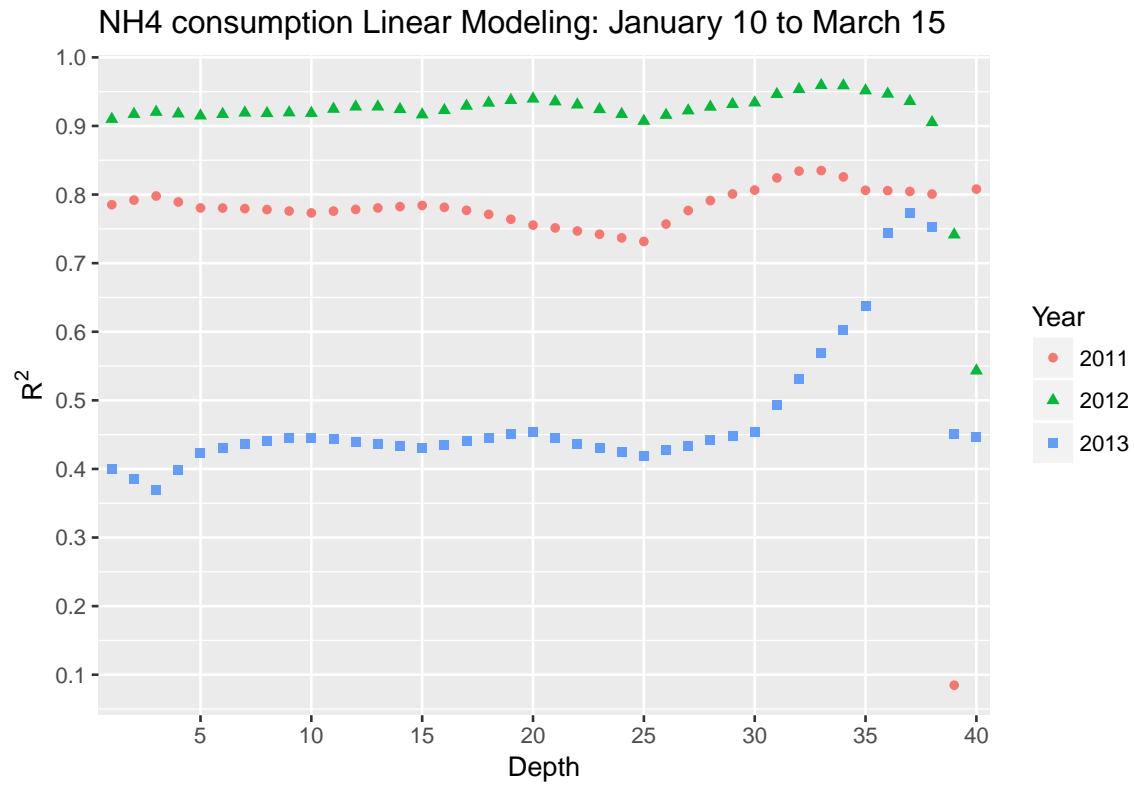
b parameter for NH4 build-up: April 30 to December 1



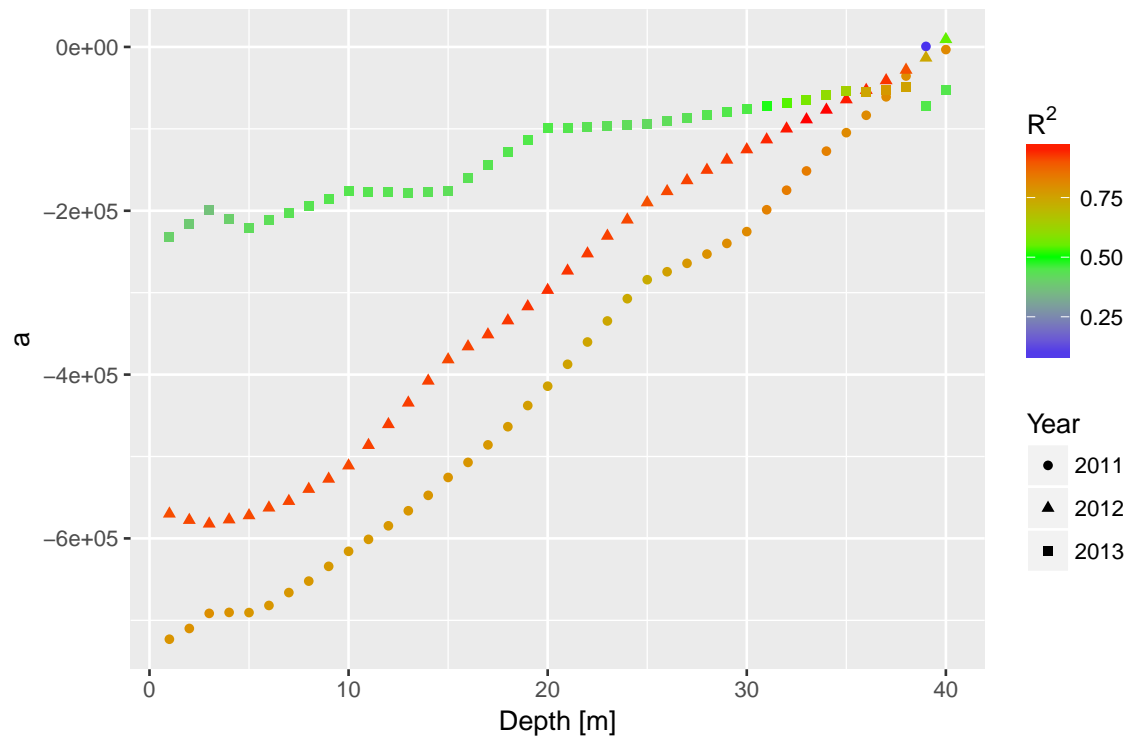


Ammonium consumption after mixing between January 10th to March 15th

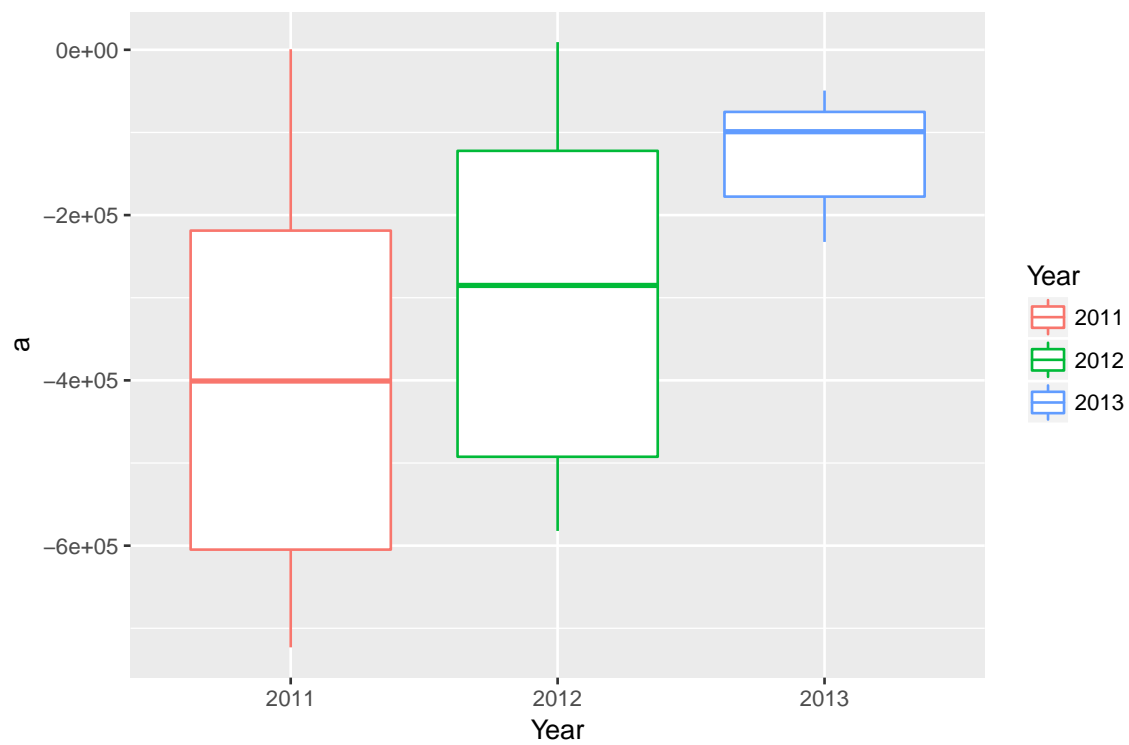
##	Depth	a	b	r2
##	Min. : 1.00	Min. : -723066	Min. : -9510	Min. : 0.08467
##	1st Qu.: 10.75	1st Qu.: -443545	1st Qu.: 5888522	1st Qu.: 0.45085
##	Median : 20.50	Median : -200589	Median : 10710844	Median : 0.77990
##	Mean : 20.50	Mean : -272712	Mean : 17447156	Mean : 0.71780
##	3rd Qu.: 30.25	3rd Qu.: -96653	3rd Qu.: 29659587	3rd Qu.: 0.91716
##	Max. : 40.00	Max. : 9290	Max. : 46089838	Max. : 0.95925



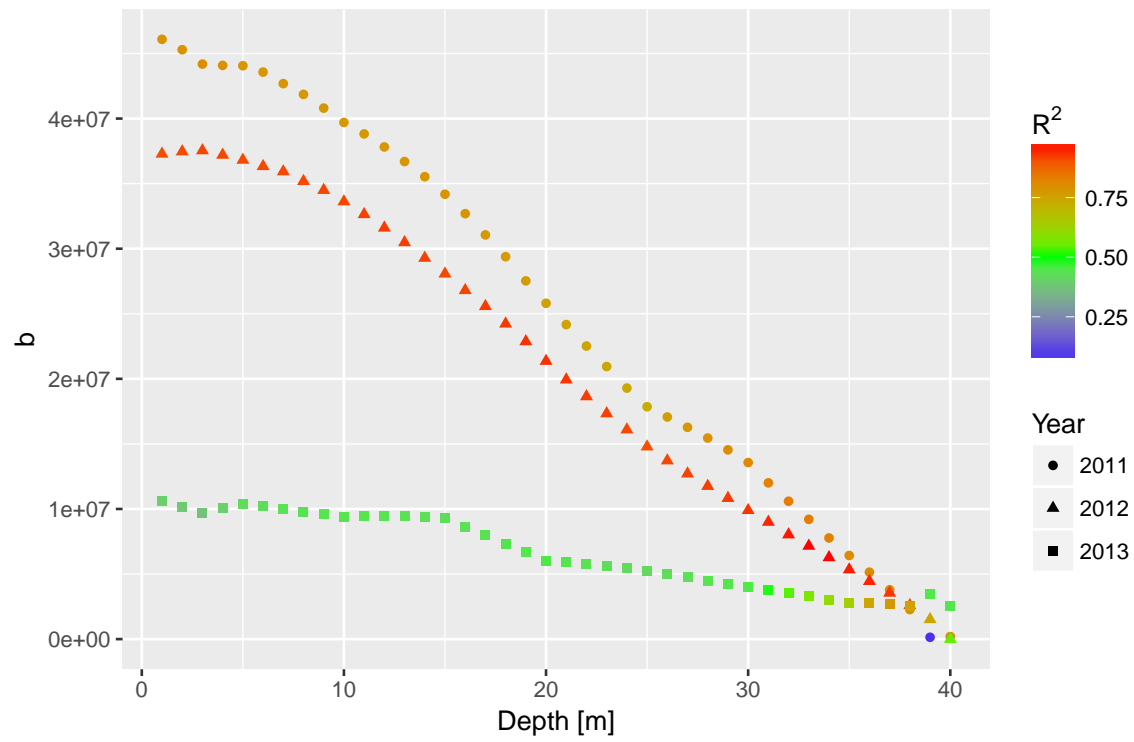
NH₄ consumption Linear Modeling: January 10 to March 15



a consumption for NH₄ build-up: January 10 to March 15



NH₄ consumption Linear Modeling: January 10 to March 15



b consumption for NH₄ build-up: January 10 to March 15

