University of Exeter

ECM3735 Mathematics Group Project

Vegetation and Climate: Investigating Seasonality at Hyytiälä in Finland.

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Contents

Abstract

At the beginning of our project our main aim was to improve the representation of seasonality in the JULES model for our site of choice, Hyytäliä. This means improving how accurately latent heat flux (LE) is modelled by JULES. This would be achieved by finding which variables were most closely associated with latent heat flux, using FLUXNET data, then enabling us to identify which processes were most closely linked to latent heat flux at Hyytäliä. After this the parameters in the equations that represent these processes, in JULES, were optimised using ADJULES to provide us with a new model. We then concluded that the new model meets our initial aim and then validated our results by showing that the optimised parameter set improves the representation of seasonality for other years as well.

1 Introduction

1.1 Main Aims

The main aim of this project is to improve the representation of seasonality in JULES for our chosen site, Hyytäliä. To do this we will study how accurately JULES models latent heat flux, in comparison to the observed data for this, to indicate how well the JULES model is performing. We will then use the data recorded at the FLUXNET tower to investigate which climatological variables are most strongly correlated with latent heat flux (LE); where latent flux is the heat from the Earth's surface to the atmosphere that is assosciated with evaporation of water. This will enable the identification of the processes that are most closely linked to LE at our chosen site. Then, using ADJULES, we will optimise the parameters in the equations, in JULES, that represent the processes that have been identified as important. This should improve the representation of seasonality in JULES, meaning that the modelled time series for LE is closer to the observed time series throughout the year. We will then aim to validate our results by using the optimised parameter set we have obtained for one year, to create a new modelled time series of LE for a separate year. Then, if this new model produces a more accurate representation of seasonality than the original model, our aim will have been achieved.
One problem noted by Eleanor Blyth in her 2010 paper, table 2 was that the JULES models was too low in winter and too high in summer. Also from Blyth 2010, figure 2, we can see that the modelled time series for LE increases greatly before the observed time series. By optimising the parameters in the JULES model, for the most important processes, we will hopefully improve the representation of seasonality in JULES and therefore solve this issue.

1.2 Background Information

1.2.1 FLUXNET

Throughout our project, we will be using data which has been recorded at FLUXNET towers. FLUXNET is the broad term which encapsulates all the variables being measured at a particular site. The towers are equipped with eddy correlation instruments which measure the turbulent fluxes of water, heat and carbon dioxide. To facilitate this, the towers are located between 2 and 10 metres above the canopy of the vegetation or the land surface. These fluxes are routinely measured from an area about one hundred metres upstream of the instrument every half an hour to give extensive data on the specific area. (Blyth, 2010)

At each site there is a single FLUXNET tower (sometimes called an eddy covariance tower) that measures what is happening at ground level. Although it is very beneficial having all the data produced at one tower it can lead to a generalisation of a whole area of vegetation at a single point, we will go on to discuss this later in the project. An example of a FLUXNET tower is shown in the images below:



[4]

These photos show what FLUXNET towers in a needle leaf forest look like. Although photos of the Hyytiälä site were unavailable we think this gives an accurate representation for our readers to imagine when we discuss these towers throughout the report. As you can see, towers are positioned in such a way that they are above the canopy of the forest and thus take a reading from an area of trees/ vegetation rather than a single organism. In this way, although the tower is still technically only measuring meteorology from one point, we can extrapolate to assume these readings would be the same (or similar) for a whole area of forest. To make our project more detailed and specific we decided to concentrate on a single site. Through research and discussion with our project supervisors we decided to research the Hyytäliä tower in Finland. We chose this site for a variety of reasons.

Firstly the vegetation was all of a single type, Evergreen needle leaf trees.

This will allow us to carry out extensive specific research and make more certain conclusions as we will not need to consider the impact of differing vegetation on our results. Secondly, there are 10 years of data recorded which is only exceeded by one other site. This is a large enough spread for us to ascertain whether there are any patterns in the data over time and choose to study certain years which appear to have specifically interesting data. Our contact supervisor explained how in particular the Harvard forest was a well researched forest with a lot of data and an area in which she had a fair amount of specific knowledge. However, we decided to try and contribute to possibly help improve knowledge and analysis in a different area, in our case Hyytäliä.

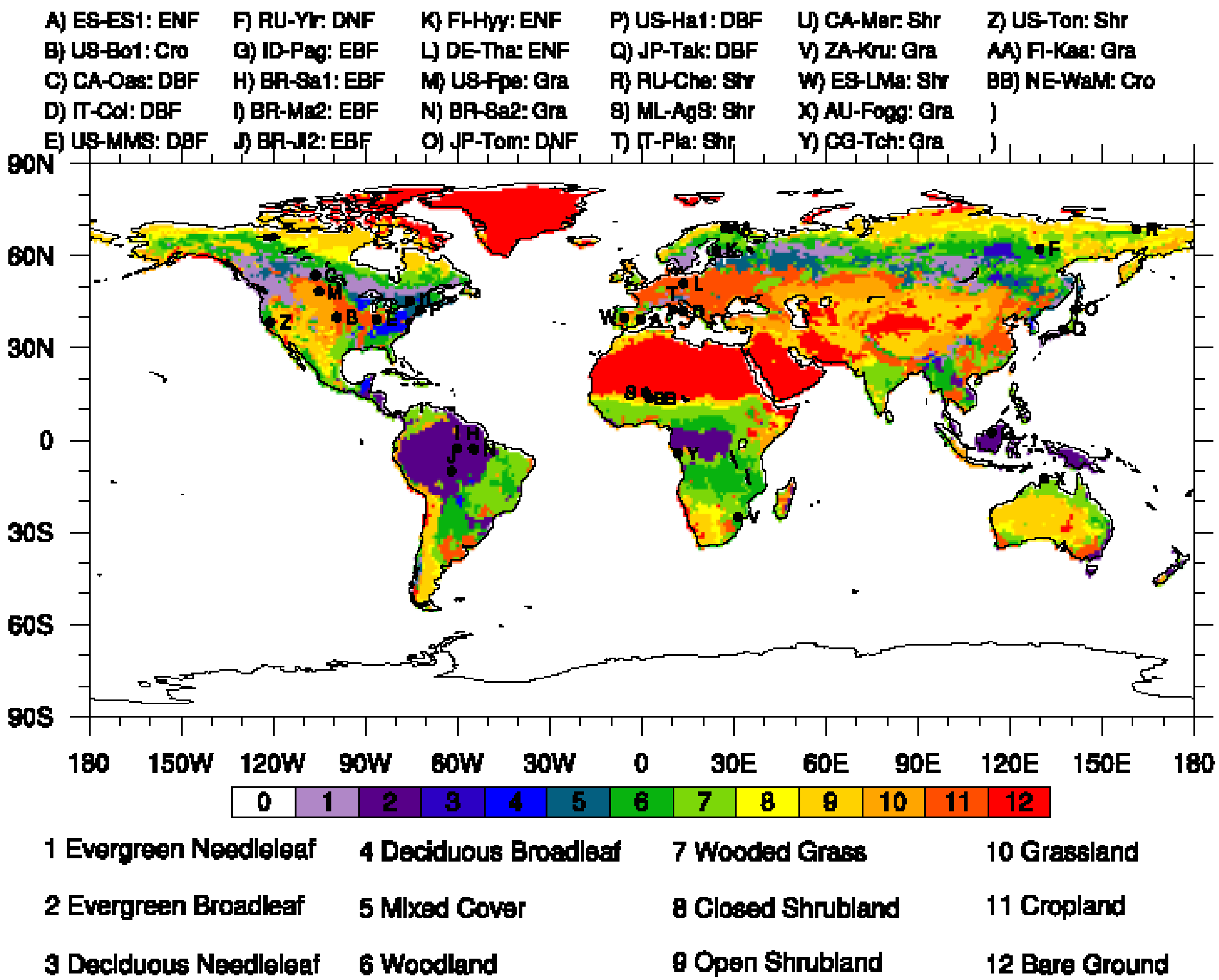
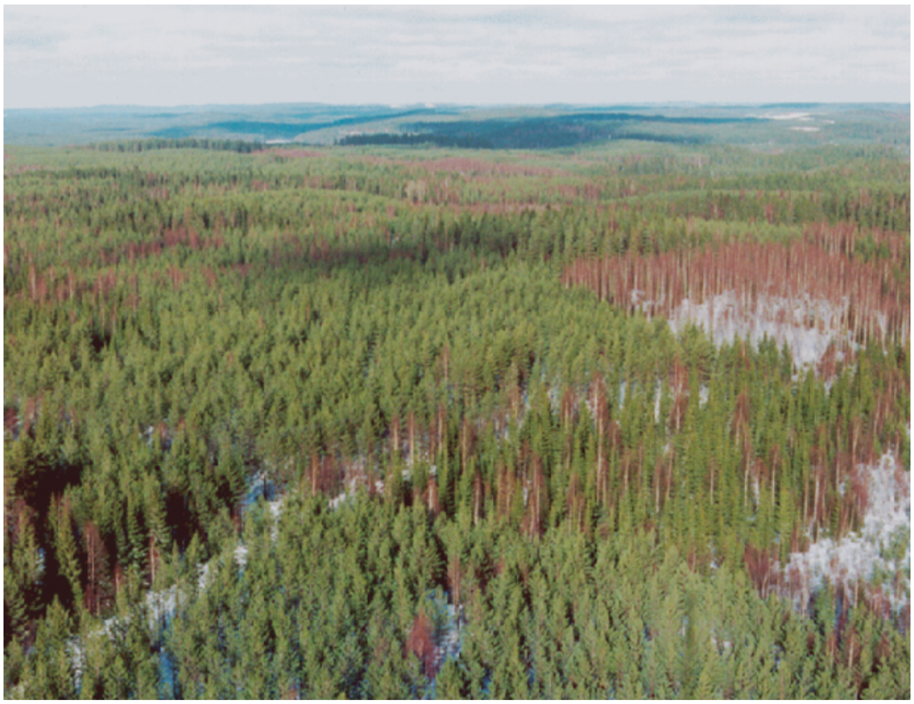


Figure 1: Global map showing the potential towers we could have chosen, their location and the type of vegetation found at each site. Hyytiälä is shown by point K [14]

Figure 1 is a global map showing the potential towers we could have chosen, their location and the type of vegetation found at each site. Hyytiälä is shown by point K.

[5]

An overhead view of the Hyytiälä forest, Finland. This shows clearly the dominant vegetation type, Evergreen needle leaf trees

1.2.2 Land Surface Parameterisations

Some of the most important roles in a climate system are radiation, sensible and latent heat, these are given by;

$$R_n = G + H + \lambda E \tag{1}$$

$$H = \frac{T_s - T_r}{r_a} \rho c_p \tag{2}$$

$$\lambda E = \beta [\frac{e * (T_s) - e_r}{r_s}] \frac{\rho c_p}{\gamma} \tag{3}$$

[7] Table 1 lists the variables used in the 3 equations.

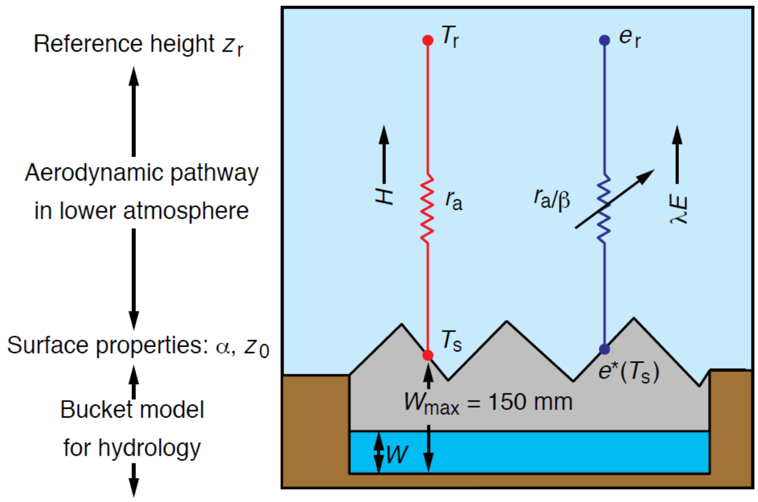
Table 1: Table of Variables

Symbol	Variable
R_n	Radiation
G	Ground Heat Flux
H	Sensible Heat Flux
λ	Latent Heat of Vapourisation
r_a	Aerodynamic Resistance
ρ c_p	Density and Specific Heat of Air
T_r	Air Temperature
T_s	Land Surface Temperature
E	Evapotranspiration rate
e_r	Vapour Pressure
e^*T_s	Saturated Vapour Pressure at Temperature T_s
β	Moisture Availability Function
γ	Psychrometric Constant

Models used in climate simulation at a basic level require the surface fluxes of heat, radiation, momentum and water vapour. Fluxes are calculated using sub models known as “land surface parameterisations”. These land surface parameterisations (LSPs) have advanced from predicting specific fluxes to fully describing a detailed range of interactions between the land and atmosphere on a wide scale. The first LSPs were developed in the late 1960’s (Sellers et al, 1997).

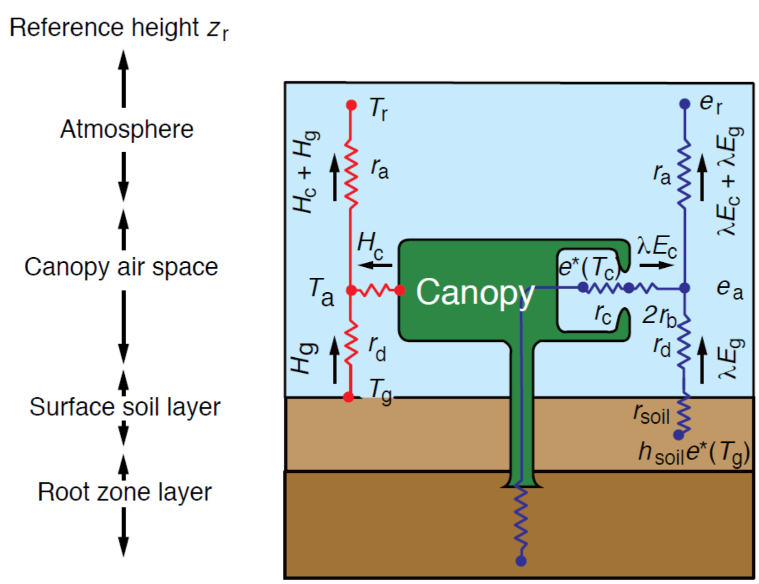
The second generation of LSPs had been introduced in the late 1980’s; these sub models “explicitly recognised the effects of vegetation in the calculation of the surface energy balance” (Sellers et al, 1997). The third generation uses recent theories regarding plant water relations and photosynthesis. This allows a consistent and accurate description of evapotranspiraton as well as carbon and energy exchange by plants.

To explain how recent LSPs work it is worth explaining previous, simpler models and building an understanding from this, these LSPs have been incorporated by Atmospheric general circulation models (AGCMs). The diagrams included show the evolution of LSPs in AGCMs;



[6]

This is the first generation model, known as the "bucket" model. This is relatively simple, latent fluxes and sensible fluxes flow from the surface up to the atmosphere. While this process is occurring the fluxes have to travel through aerodynamic resistance. The level of moisture, W, regulates the latent heat flux in the bucket. This is done through the moisture availability function, β, which is always between (or equal to) 0 and 1. Here, α and z_0 are surface parameters, which are normally regarded as global, (usually) uniform fields, and W_{max} is set to a typical single value, around 150mm.



[6]

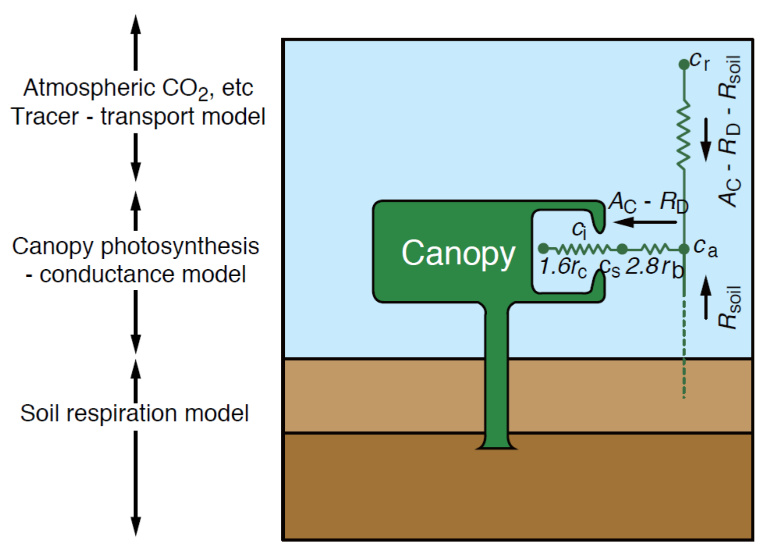
The second generation model has a separated soil and vegetation canopy. From the vegetation canopy moisture fluxes escape towards the free atmosphere and the air canopy, this occurs through a surface resistance from a bulk canopy, given as r_c where;

$$r_c = \frac{1}{g_c} \tag{4}$$

g_c is an estimate of conductance at a canopy-scale, which is obtained from the leaf scale model;

$$g_s = g_s(PAR)[\psi] \tag{5}$$

Where g_s is the conductance of a leaf, g_s(PAR) is the conductance of a leaf regulated by PAR, PAR is the light emitted from the sun. ψ is a series of environmental stress factors that consider vapour pressure, leaf water potential and temperature. Latent heat and sensible heat fluxes from the ground (with subscript "g") and fluxes from the canopy (with subscript "c") are combined in the space occupied by the air canopy to give all the fluxes passed through the atmosphere.



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The third generation model adds a carbon flux pathway to the heat flux and moisture pathways, which is shown in the second generation model. The canopy model can simultaneously control carbon and water fluxes consistently. This

model is most recent and the theory used behind the LSPs and the calculations behind AGCMs allows us to understand how our project will unfold.
The LSP we are using for this project is known as JULES.

1.2.3 JULES

We will be using the software JULES and ADJULES in our project to formulate and analyse our models of the Hyytiälä site.

The Met Office describes JULES as a "land surface model for the UK research community which can be directly linked into the Unified model" (2010). JULES is a tool that allows people to analyse land surface processes globally. For this project however it will be focussed at a specific point (tower), so that we can use the data produced to represent the rest of the area.

JULES itself is based on Moses (Met Office Surface Exchange System), which is in turn the surface model used in the Unified Model of the Met Office (Met office and Centre for Ecology and Hydrology, 2011). The Unified Model is a numerical modelling system, developed and used by the Met Office, whereby a single model can be used for predictions across a variety of timescales and areas (Met Office, 2010). The Unified Model can be applied on land surfaces (JULES), ocean models, wave models, chemistry and Earth system components (Met Office, 2010).

JULES analyses separate surface temperatures, short wave and long wave radiation fluxes, sensible and latent heat fluxes, ground heat fluxes, canopy moisture contents, snow masses and snow melt rates (Met office and Centre for Ecology and Hydrology, 2011). JULES recognises nine different surface conditions; broadleaf trees, needle leaf trees, temperaturate grass (C3), tropical grass (C4), shrubs, urban, inland water, bare soil and ice (Met Office and Centre for Ecology and Hydrology, 2011). We chose Hyytäliä as it has an almost entire needle leaf tree body, this will allow us to model for on plant type.

1.2.4 ADJULES

We will also be using the data assimilation program ADJULES to develop our models and parameters. "The ADJULES data assimilation system uses information from the derivative of JULES to search for the best parameter set by calibrating against observations" (Luke and Jupp,2011). This means that when you program in the relevant functions of JULES it will proceed to derive the optimal solution. Once it has found these parameters, they will then be applied back into the JULES modelling system so that the new optimal parameters will hopefully improve the accuracy the developed model.

1.3 Relevant Research

1.3.1 Our Understanding of Hyytiälä

Hyytiälä forestry field station is located in the Pirkanmaa region in Finland. The site had Scots Pine (Pinus sylvestris) planted in 1962, the site consists almost entirely of evergreen needle leaf trees, including the planted Scots Pine. The site has a lack of variety in terms of not only trees but vegetation, consisting almost entirely of evergreen needle leaf vegetation. There are some gaps in particular years as is the case with most ongoing sites due to various factors. It is worth noting that in 2002 between January and March the forest was thinned by an area of $4.33ha$ (hectares) [16] due to forest management guidelines. Before thinning, trees had an approximate height of 14m. Additionally, the all-sided needle area $8m^2/m^2$ and after thinning the area was $6m^2/m^2$ [16] the tree biomass is currently around $68t/ha$ (tonnes per hectare) above as well as below ground. The site's current function is to assist in the teaching and understanding of forestry. The tower was set up to collect meteorological data, including precipitation, temperature, wind speed and many other variables. The variables we are focusing on are related to latent heat flux. The data recording started from 1996 and has been recording up to 2011; the towers height is 73m and is located at coordinates (61.8474N 24.2948E).

The climate of Finland (and in particular Pirkanmaa) is classed as "Dfc" according to the Koppen climate classification system which is simply a common form of subarctic climate. The winters are severe comparable to Alaska, last a long time and are very cold; snow can lie on the ground for an average of between 90 and 120 days [15]. Summers are much warmer than one would think especially in the south, comparable to Denmark or southern parts of Sweden. In the Pirkanmaa and neighbouring regions there is mostly low-lying land consisting of many lakes and pine forests. On the whole, the weather is very varied. Weather in Finland is affected to by Atlantic weather perturbations.

1.3.2 Previous Research

Further research on the Hyytiälä site has already been done. However, the aspects that they focus on differ from what we have studied.

For example, the Suni et al. paper, written in 2003, explores several different areas to do with surface fluxes in Hyytiälä between 1996 and 2001. The paper investigates the annual and diurnal flux patterns of sensible heat, momentum, carbon dioxide, water vapour and aerosol particles. It then goes on to determine the annual cumulative NEE and to examine whether human pollution, both near and far from the Hyytiälä site, had any affects on the fluxes.

Suni et al(2003) found that seasons were influential to most fluxes, for example, sensible heat, water vapour and carbon dioxide were all smaller in the winter than the summer. Diurnal patterns were also found; for certain fluxes different times in the day would always produce maximum or minimum results. They also noticed that some processes would decrease or increase simultaneously, such as respiration and photosynthesis. All human pollution had a substantial effect on the fluxes and so on carbon dioxide and aerosol particles, they found the effect to be greater during the winter months when more pollution is produced through the use of heating and more lighting. They also learned that new particle formation was seasonal, the majority happened during the spring with a few happening in summer and autumn. These previous studies involved purely the observations from Hyytiälä. Blyth et al (2010) used JULES at the site (as previously mentioned), but this is the first time parameter optimization has been carried out for a model at Hyytiälä.

1.4 Report Structure

Our report will be structured with 3 main components; Methodology, Findings and Conclusion. This will be followed by a bibliography of our sources.

Firstly our Methodology will contain details of how we are splitting up our workload, including group members' strengths and weaknesses, and how we will play to them. This will be followed by an analysis of our given data; exploring limitations, errors, how we dealt with them and how reliable it really is. We will then discuss the process of how we will choose the parameters we believe are most important and how we will attempt to optimise them. We will then need to analyse our optimised parameters to see if they are, indeed, better. At each stage we will explain any computation using software such as R, JULES and ADJULES at a level that is accessible to mathematics students.

Our findings section will contain explanations and visual representations of our findings in both graphs and tables, for example correlation scatter plots between latent heat flux and other observed variables. This will also be an opportunity to point out any challenges or errors in our findings, how we coped with them, and also how (if we were to repeat the process) we would do things differently in the future. Furthermore we will analyse our list of resources to show the reader we have good evidence to back our findings up.

Finally in our conclusion section we will, by definition, be concluding what our findings mean, how relevant they are and how useful they are in the field of land surface modelling. We will discuss any implications from our research and analyse whether further research need be done. Again, this may involve re-evaluation of our original data set and optimized parameters. This will ensure we have reached a sound conclusion.

2 Methodology

2.1 Research

2.1.1 Structural Organisation

To begin, we decided it would be beneficial to read some background information about this project to gain a better knowledge of the science involved, understand the time constraints we had and to learn about similar research that had already been undertaken. We read several papers that followed a similar structure to this project at different sites around the world.

This gave us an understanding of what was to be achieved from this project and how the programs JULES and ADJULES would come in use. We learnt that JULES can be used to model a time series for a year's worth of latent heat data. ADJULES could then be used to optimise the parameters in equations that represent the processes, in JULES, that we had identified as important.

This research was carried out by Chris, Annie, Charlie, Tom and Alex. In doing this they not only gave our project a clear direction, but improved their personal skills of researching and gathering information. They also improved analytical skills by pinpointing relevant information for our project from papers that were often written for experts in the field and therefore contained a lot of information that was too complex for the level of depth of the project.

A particularly tricky bit of reading that we had to learn about was how different methods of creating models work. These are called LSMs (Land Surface Models) and gave a few of us a challenge to not only understand them (through multiple papers and websites) but then re-write them and explain them so that the rest of the group and the readers of our report could understand.

Once this research was completed and the group as a whole understood the project better we could start on the bulk of the project; our data analysis.

2.1.2 Stomatal Resistance & Latent Heat Flux

After some research we found that latent heat is related to the stomatal resistance. If the stomatal resistance is low then the stomata themselves are larger and thus the uptake of carbon dioxide is greater; this results in photosynthesis occurring at a quicker rate.

"In plants with adequate water supply, the stomatal opening reduces drastically the water exit resistance from the inner of the leaves towards the atmosphere. In these conditions when the guard cells receive solar energy there will be fixation of CO_2, with a consequent reduction of CO_2 concentration in the inner of the cells resulting in H^+ active excretion and quick K^+ absorption and subsequently, stomatal opening." (Joasen, 2006)

We will also look at the factors which control stomatal resistance as this controls how open the plants' stomatal are and thus how much gaseous exchange can take place. Our research will look into the main factors which affect stomatal resistance such as temperature, wind speed, etc as this will be the main way we can tell whether photosynthesis is occurring and at what rate.

As mentioned previously, the formula for latent heat flux is quite complex, equation 6 shows latent heat flux in terms of stomatal resistance.

$$LE = \frac{P}{r_a + r_s}[Q_{sat}(T^*) - Q_1] \tag{6}$$

In this equation r_s is the stomatal resistance and $Q_{sat}(T^*)$ is the saturation point, which is the humidity.

With a low stomatal resistance, the stomata are open for an increased loss of water vapour "The variation in the stomatal pore opening will simultaneously lead to the CO_2 entrance control to the leaf and water vapour release. The stomata resistance to diffusion increases greatly with the reduction of the pore opening." (Larcher, 1980) We chose to optimise against latent heat because it informs us about vegetation functioning due to the close relationship to stomatal resistance.

2.2 Observations

When we started analysing the large amount of data that we had available to us from the FLUXNET tower in Hyytiälä, we looked specifically at the data from the years 1996 to 2005. From this we observed that the year 1998 was particularly cold. Whereas, we found that the temperatures in 2003 were above average during the summer months. Therefore we decided that these two years would be beneficial for us to compare, enabling us to see which were the most important processes governing the level of latent heat flux were at different temperatures. In addition to these years we chose to study the year 2001, as a control, because the mean temperature that year was close to the overall mean of the entire data set. It would also enable us to see if there was any trend in the data over the period 1998 to 2003.

After this initial choice of years, we went about finding which variables were most strongly correlated with LE. This was done by plotting graphs of different variables against LE. After identifying which variables were most strongly correlated with LE, we could identify which processes were most important in governing the level of latent heat flux at our chosen site. We could then optimise the parameters in the equations that represent these processes, in JULES, using the ADJULES software.

By optimising the parameters using ADJULES, we are aiming for the modelled time series from the optimised model to be closer to the time series of the observed data, than the original JULES model. As shown by Eleanor Blyth, in her 2010 paper, the modelled time series for LE, at Hyytiälä, increases greatly before the observed time series begins to increase for the year she was investigating. This suggests that JULES takes spring to be too early at Hyytiälä. Therefore, we want to explore why this might be the case and correct the error.

Scatter plots and correlation coefficients of each available variable against LE were then produced for the years 1998, 2001 and 2003, as shown in figures 4, 5 and 6. The variables included many meteorological readings measured by the FLUXNET towers such as air temperature, wind speed, rainfall, the amount of short wave and long wave radiation and net radiation, among others.

From these plots and calculations we could observe which variables were most strongly correlated with LE and therefore could identify which processes were most influential on LE. In each case we found the average correlation, between LE and each of these variables, over all 3 years. The variables that had the strongest correlation with LE were photosynthetically active radiation (PAR), net ecosystem exchange (NEE) and Gross Primary Productivity (GPP). PAR is simply the energy used by plants when they photosynthesise. The variable Gross Primary Productivity (GPP) was also strongly correlated with LE. However, data for GPP was not available for all of the three years in our study. GPP is defined as the estimate of the amount of organic compounds created from carbon dioxide through photosynthesis. We also discovered that Latent heat flux is defined as the movement of water vapour through the stomata (small "holes" on the leaves of the vegetation) which are opened during photosynthesis.

When a plant photosynthesises the stomata opens, to allow the absorption of carbon dioxide (a vital reactant in photosynthesis), through which water vapour will diffuse. We found the correlation between GPP and LE for the years 1998 and 2001, for which data of both variables was available. The average correlation between the two for the years 1998 and 2001 was 0.869 for GPP and LE, displaying a strong positive correlation and justifying that the two are closely linked.

From the strong correlation shown between PAR and LE and GPP and LE, we could deduce that the process of photosynthesis is strongly linked to LE. Therefore, the decision was made to optimise the parameters in the equations that represent photosynthesis within JULES to see if the model could be improved upon. At this point further research was done into photosynthesis, gaining a greater understanding of the process and the factors governing the rate of photosynthesis.

These steps of the project, namely the initial exploratory data analysis and analysis of the correlations, were carried out by Joe and Mike. These members of the group were chosen because both of these group members were comfortable using R, a statistical software package. They had had experience of using this program in the past. It also meant it allowed them to continue learning about this software and they gained a greater working knowledge of R.

R was the software that was used to read the data containing the measurements for all the climatological variables, produce scatter plots and find correlations between LE and the other variables. This part of the work also helped Joe and Mike gain skills in data analysis when they used the graphs and correlations that were produced, to identify which climatological variables in the data set were most closely linked to LE.

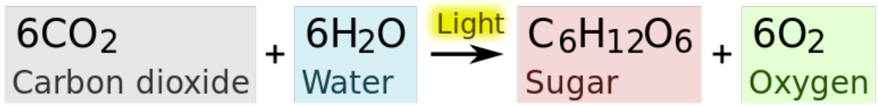
As a group we gained skills in data analysis as we all played a part in deciding which processes were the most important in governing the level of latent heat flux and why. We also noticed the limitations in the data, in particular the lack of GPP data for all years, amongst other gaps in data and difficulties with understanding.

At this stage of our project, our project supervisors ran the JULES software to provide us with a year long time series of data for LE.

2.3 Photosynthesis

A large section of the project focuses on the process of photosynthesis and what factors influence it.

A simplified equation for photosynthesis is given by:



[1]

Photosynthesis also requires *a complex set of physical and chemical reactions to occur in a coordinated manner for the synthesis of carbohydrates.* [2]

Essentially, this is a process used by plants to "*convert the light energy captured from the sun into chemical energy that can be used to fuel the organism's activities*" (Author unknown, 2010). A critical aspect of global climatalogical process is photosynthesis. Photosynthesis absorbs carbon dioxide from the air and produces oxygen, which will then be released into the atmosphere. This provides aerobic organisms with the oxygen they need to respire and survive.

From earlier, we know that when the stomata are wide open, plants absorb more carbon dioxide; this subsequently reduces stomatal resistance which allows the plant to achieve photosynthesis at the highest rate. This also means that the plant lets out the most water during the period of low stomatal resistance, which is why we are reading the measurements of latent heat flux. Additionally, this explains why there is such strong correlation between latent heat flux and photosynthesis. The energy required to commence this process of photosynthesis is sunlight. The most desirable wavelength is shortwave radiation.

2.4 Parameter Optimisation

Having generated a year's worth of data the next phase of this project was to use the software ADJULES to optimise the parameters. The parameters are the constant values which govern the variables, for example 'tlow' is the lower temperature for photosynthesis. We aimed to optimise these parameters so the new optimised model would produce a time series that would be closer to the observed time series than the initial model.

Equation 7 is used for ADJULES.

$$o_t = \begin{pmatrix} NEE_t \\ H_t \\ LE_t \\ T_* \end{pmatrix}; p_t = \begin{pmatrix} NEE_t \\ H_t \\ LE_t \\ T_* \end{pmatrix} \tag{7}$$

The cost function is the weighted least squares difference of these two vectors, shown in equation 8

$$f(x) = \sum_{t=1}^{n} (m_t - o_t)^T w^T w (m_t - o_t), \tag{8}$$

where w is a 4 x 4 weight matrix, the choice of w in this project is shown in equation 9

$$w = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \tag{9}$$

(Luke, 2011)

These equations can be difficult to understand and seem intimidating at first. By remembering that most of these symbols are constants (parameters) that we are trying to optimise, we find they become easier to comprehend. The list of symbols can be found in the appendix of this project. The optimisation process was done by performing a series of iterations using R, as to do it by hand would be impractical given the weight of calculations. The series of iterations repeatedly calculates the derivative of the cost function, which can be thought of as a function representing the errors, or differences between the model and actual data. In actuality it is the sum of squares of the errors (or differences) weighted by how important the parameters are. Since this project focuses specifically on latent heat, this weight function is just 1: more variables would mean involving a more complex weight function.

We are looking to find a point where the cost function is minimised, this is when there is a turning point in the curve i.e. the gradient is zero. To do this the derivative is taken as it tells us the gradient of the cost function at that point, we can "follow the curve" downwards to the lowest point, figuratively. In actuality this is in multiple dimensions, referring to so many parameters at once, but this helps us to visualise what the program is calculating.

Having read the appropriate data into R, and set up the computer to use JULES and ADJULES, the iterations can now run to optimise the parameters in the model. This task was started as a group, giving everyone the opportunity to learn to use Linux computers and running the iterations on R, neither of which any of the group had done before. However, as it was so time consuming it was completed by Becca. Having done this we were able to plot the time series of the observed data, the initial model and the new optimised model against each other to help analyse whether the optimised model was infact better. Plots for the errors in the time series were also produced, allowing us to see the differences between the modelled time series and the observed time series.

Console commands in R can seem overwhelming but upon use you understand it is just showing you the values reached after each iteration it becomes much clearer. See figure 2.

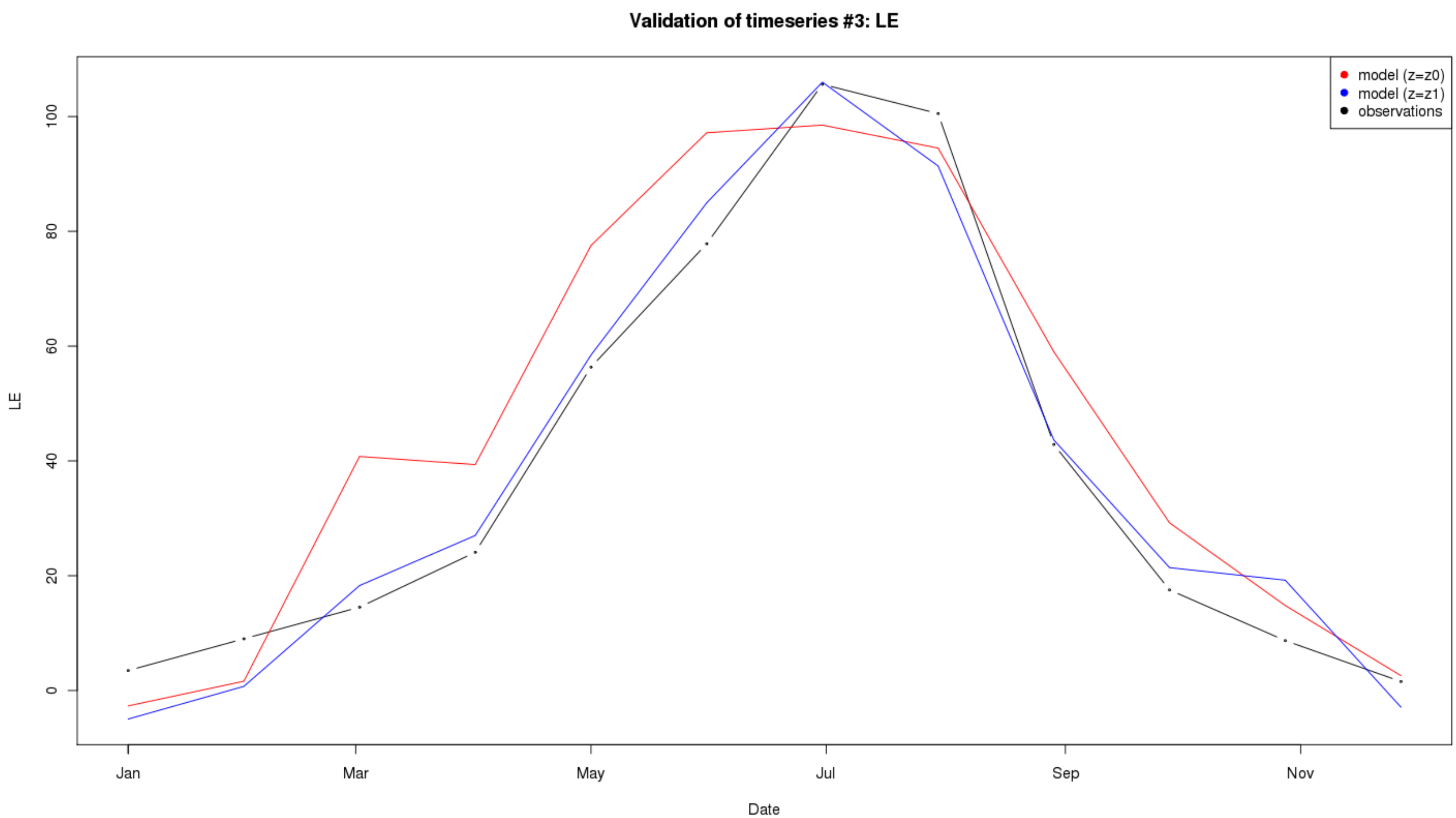


Figure 2: Time series of LE in 2001

We can use this data in figure 2 to plot graphs to see how our old model compares to our new model, and the actual data we are trying to fit it to. Clearly, the new model seems to fit to the original data much more effectively than the previous model, which is what we are trying to achieve.

We can also look at the errors in the time series, meaning the difference between the model and the actual data, shown in figure 3.

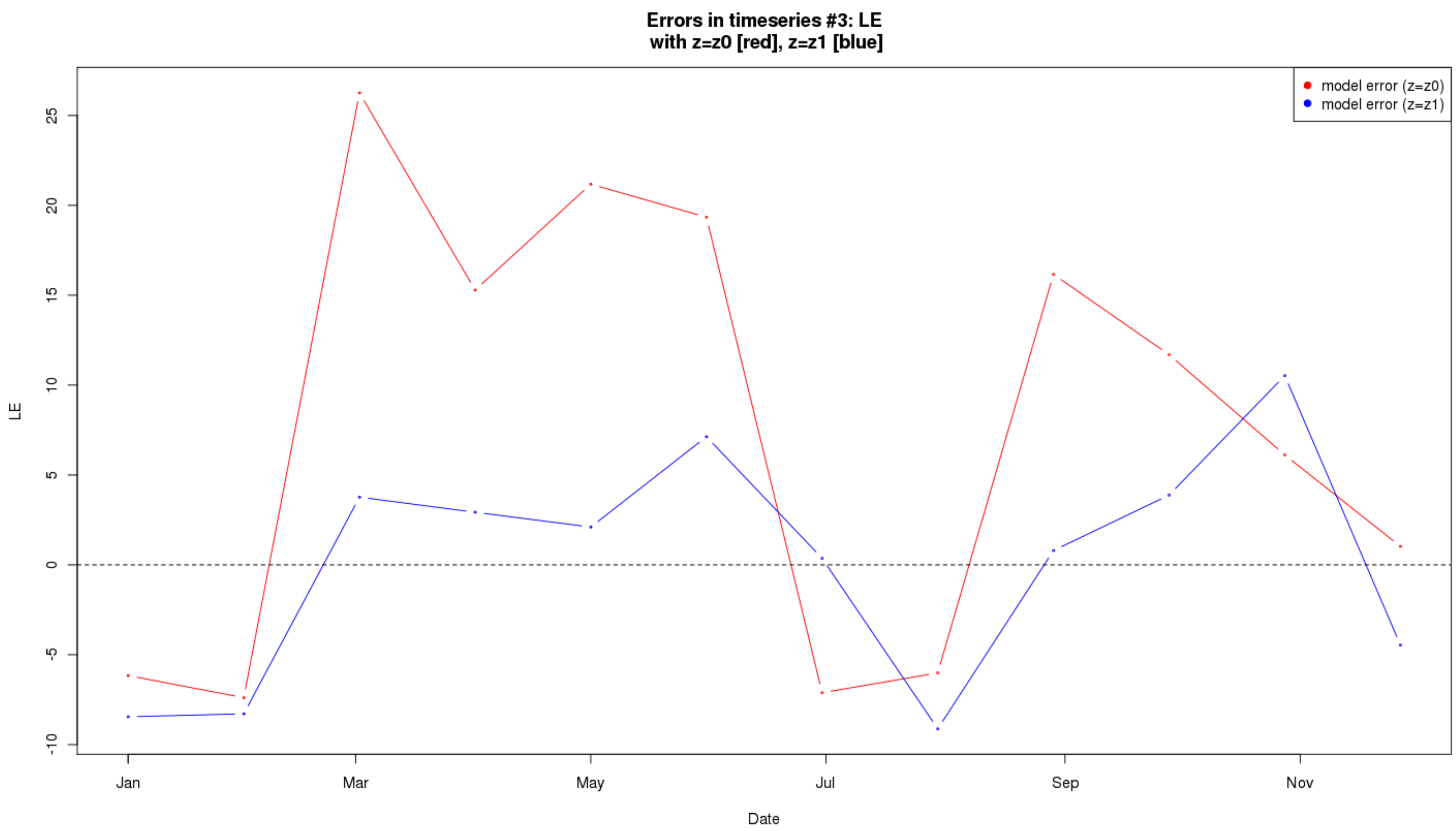


Figure 3: Errors in time series of LE in 2001

2.5 Validation And Comparison

We chose to optimise the parameters in JULES for the year 2001. This was because the temperatures in this year were nearer the mean of the time span we chose to study. Having optimised the parameters for the year 2001, a time series from this optimised model could then be produced. Using the new parameters we plotted similar graphs for the years 1998 and 2003. This would help the analysis of whether the new model did a better job of modelling LE. In simple terms: if the time series produced by the new model was closer to the time series of the observations than the initial model, the optimised model is better.

From these plots we were able to tell if the same processes governed the rate of latent heat flux in each of the years of our study. If this was the case the optimised parameters from the year 2001 would reduce the errors between the observed time series and the new model for the other years as well. This would help to justify our results and make them more reliable. The discoveries we made from analysing the graphs produced is presented in our findings section of this report.

As a group we analysed the graphs and results together, in doing so we gained skills in analysing graphs and determined what we could conclude from them. Furthermore, we learnt to question our findings as well as giving explanations about why our results appeared as they did, this is discussed further in our findings section.

2.6 Achievements as a Team

Throughout the duration of this project, as a group, we have gained a range of invaluable skills. Many of these skills were not linked specifically to a task during the undertaking of the project but were still important in ensuring a finished report. The most important skill, being obvious yet understandable, is learning to work as a team.

This is evident by the fact that we have suitably split up the workload to fit each individuals skills set, liaised with each other regularly throughout the project to assess the progress made, as well as coming together as a group to compile the final report. Furthermore, we improved our communication skills by setting up a Facebook group at the start of the project, enabling us to communicate easily, share our work and arrange meetings.

Through these meetings we discussed the progress of our report as a group, allocated work and received input from our project supervisors. Additionally, we gained skills in time management which was crucial to enable the timely completion of the project, particularly as we were delayed in starting the project due to the absence of our project advisors.

All together the group worked well and played to everyone's strengths, our report has shown significant evidence of this. We feel that not only have we all learnt new skills, we have improved on existing ones. This makes us confident in the results we have achieved.

3 Findings

3.1 Statistical Work in R

The data we received from the Hyytiälä site ranges from 1996 to 2005. This data was analysed using the statistical programming software 'R'. We created a script that would read all of the data and plot the relevant variables against 'LE' for the years 1998, 2001 and 2003. Afterwards, correlations were calculated for these variables against 'LE' and used to conclude which variables were most strongly correlation to LE. Initially before analysing the data we agreed that any variables with a stronger correlation than the value of 0.5 we would instantly consider to be a variable of interest.

Using R we produced figure 4 which looks at the year 1998 and the 17 different variables that were recorded, and the plotted these against 'LE'.

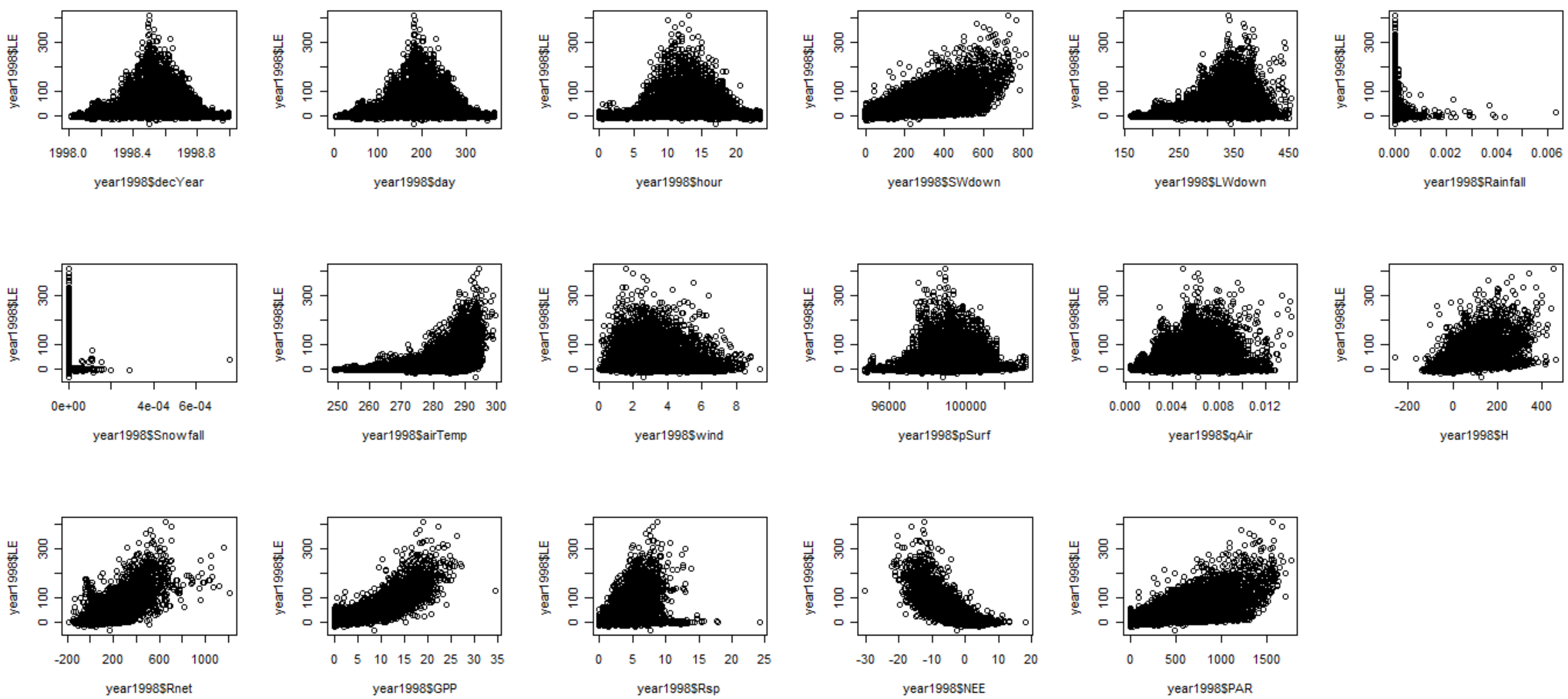
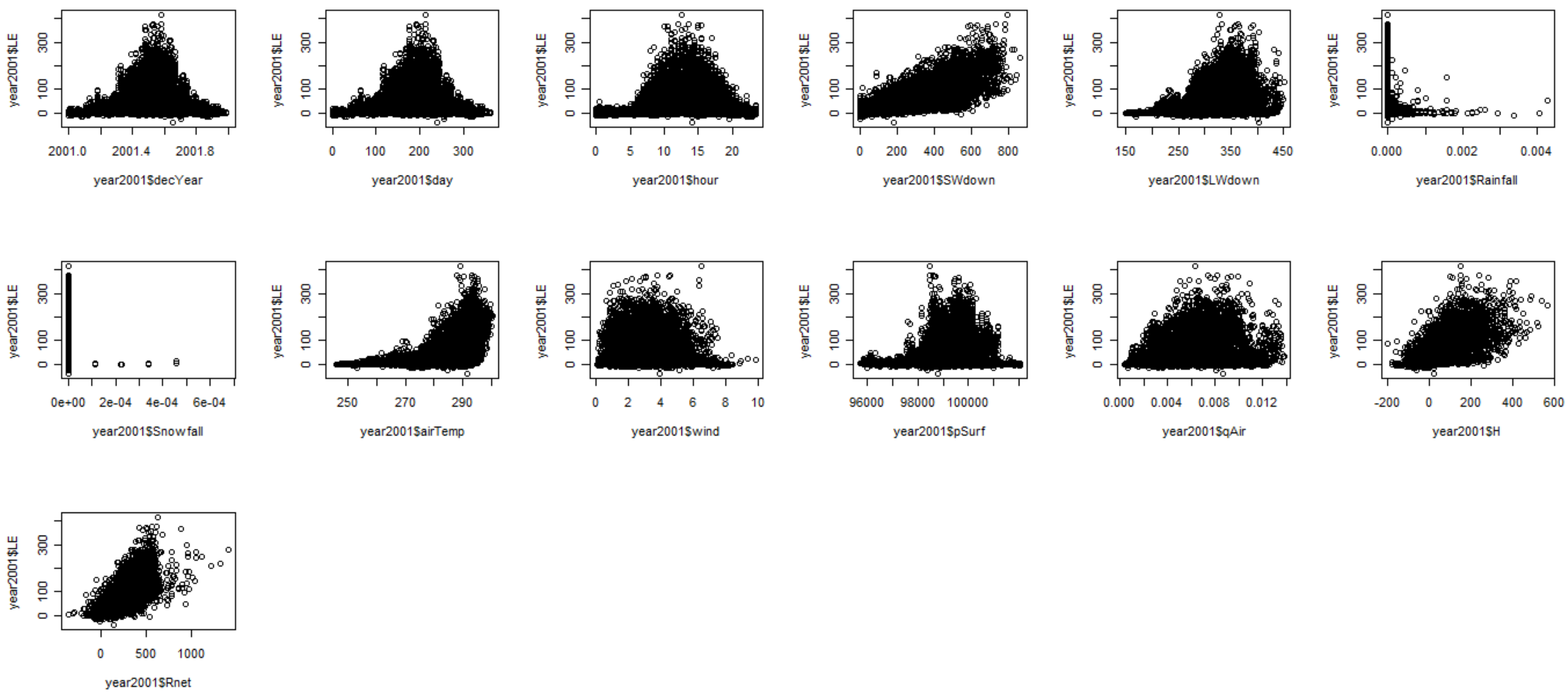


Figure 4: 1998 Variables Against Latent Heat Flux

It is obvious from the various plots that there are four, possibly five variables, that appear to have a strong correlation. To further analyse these plots we calculated the correlations of the each variable against LE which are inserted into table 2.

Table 2 shows 'SWdown', sensible heat, 'Rnet', 'GPP', 'NEE' and 'PAR' as variables with a correlation that has an absolute value of 0.5 or greater, see the appendix for an explanation of these variables.

Figure 5: 2001 Variables Against Latent Heat Flux



The data for the variables GPP, Rsp, NEE and PAR were not available between 2001 and 2005 so we were not able to compare the shapes of these graphs for different years. However, the general shapes of the other plots do appear to be very similar. If we refer back to table 2 we are able to compare the strong correlations that we identified in the year 1998 with those that we can identify in the year 2001. 'SWdown' has a strong positive correlation of 0.854 with 'LE' and likewise 'H' has a correlation of 0.718. At this stage, we can also consider the variable 'airTemp' and its correlation with 'LE'. The average value for this is 0.525 which is now above our margin of interest, whereas the correlation for this in the year 1998 was 0.488. We were convinced that taking the average of the correlated values was the sensible approach to take, to ensure that we iron out any anomalies that could occur throughout the data. Apart from the slight variation, each of the correlations appears to be the similar for each corresponding variable. Hence, we continued to see if these results continued for the final year 2003. Figure 6 are the plots of the results obtained when plotting the Hyytiälä data.

Figure 6: 2003 Variables Against Latent Heat Flux

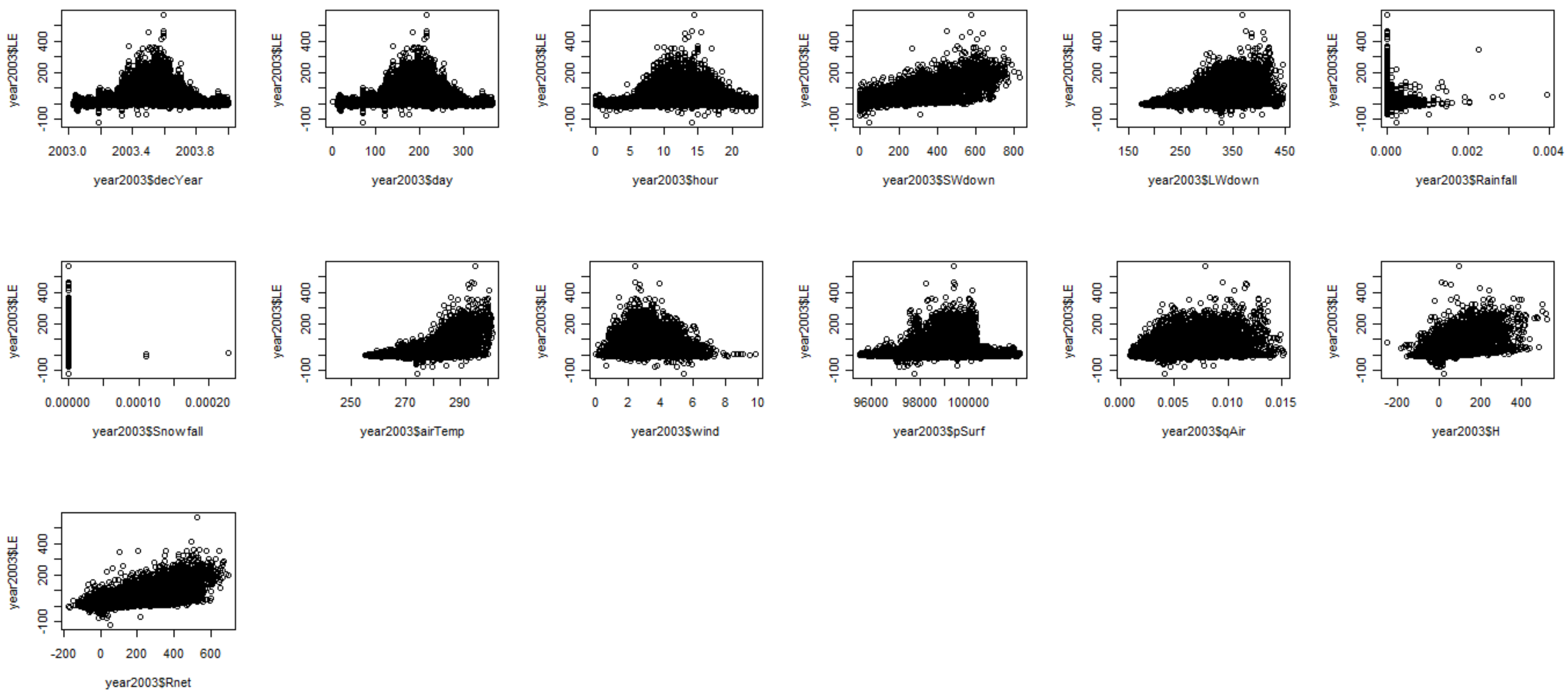


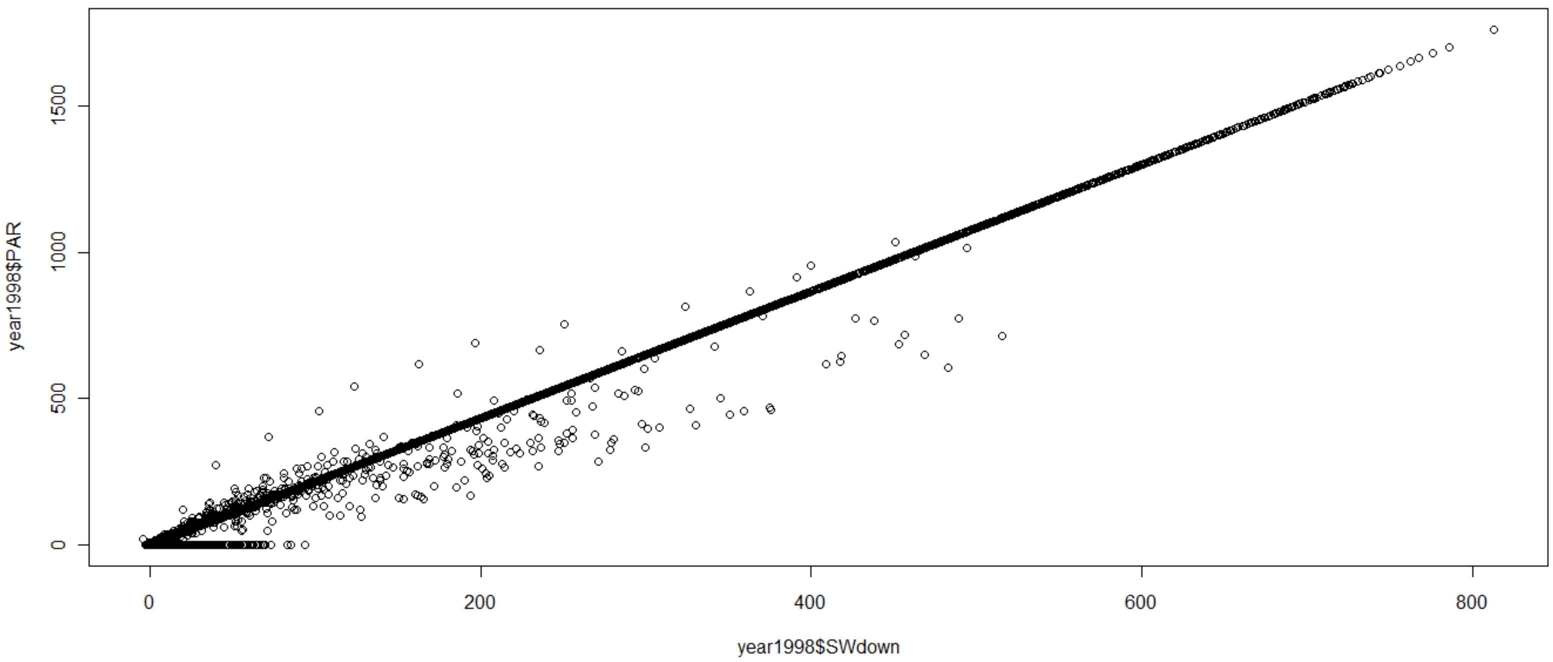
Figure 6 shows that the variations of the plots appear to be more concentrated, particularly for 'SWdown' and 'wind' plots. But when investigated further it appears the scale of the y-axis on these plots has changed to accommodate for larger anomalies throughout 2003, leaving the appearance that the data for these variables is more compacted. However, the independent correlations of the year 2003 do appear to be similar. For example 'SWdown' has a correlation against 'LE' of 0.798 which is extemely close to the value calculated in 1998.

However, there is a correlation calculated, in table 2, which has a significantly large difference between two years. For example in 2003 Humidity has a value of 0.381 whereas in 1998 the humidity's correlation against 'LE' was measured at 0.268. One reason for this may be due to the fact that the year 1998 had a particularly cold summer with an average air temperature of 286.7 Kelvin. Here we are considering summer to be the months June, July and August. This results in the low correlation for humidity against 'LE'. Whereas in 2003 the average temperature is 288.4 Kelvin which would increase the level of humidity causing it to have a greater effect on the level of latent heat flux calculated.

The colder year of 1998 would have caused a lower level of humidity in Hyytiala which, consequently did not have as much of an impact on the level of 'LE' as it did in 2003 when the temperature was higher. However after the averages of the correlated values of the variables were calculated, humidity fell below the margin of interest and so we considered this not to be of any interest. Other variables not included were 'LWdown', which had an average correlation of 0.351 against LE, for the same reason as humidity. The correlations for 'rainfall', 'wind', 'surface pressure' and 'snowfall' were concluded to be too weak; as these values were so close to 0, which suggests that they have little effect on the level of latent heat flux. This left the variables 'SWdown' which had an average correlation, shown in table 2, of 0.818, and 'airTemp' which had the average correlation 0.52.

The variable PAR, as mentioned in the introduction, is the light emitted from the sun that has the wavelengths 400-700 nanometers. It is understood that these are the wavelengths that can be absorbed by plants and used for the process of photosynthesis. With the strength of the correlation between PAR and LE, for the year 1998, we deemed it sensible to take this variable into consideration for the next step of the investigation. However, data was only available for the variable PAR for the year 1998. As shown in figure 7 the variables PAR and SWdown have a very strong positive correlation, when plotted from the year 1998. Therefore, regarding the years 2001 and 2003, we would replace the variable 'PAR' and use 'SWdown' as a proxy. This variable represents the full range of incoming radiation of wavelengths ranging from 0.1 to 5 micrometers.

Figure 7: 1998 SWdown Against PAR



Between the two variables, PAR and SWdown, the calculated correlation is 0.998, which very strong. So for the year 1998 the variable 'PAR' will be considered as it is highly correlated to LE and for the years 2001 and 2003 'SWdown' will be used as the proxy for the variable. It was acknowledged that with this approach a margin of inaccuracy may occur as 'PAR' is a subset of wavelengths in 'SWdown', but this would be so small that it was considered negligible. Furthermore, this approach is justified by the very strong correlation shown by the two variables.

For the variable 'Rnet' we calculated an average correlation, over the three years in our study, to be 0.811. This, at first, seems to be a positive result, however we have decided to ignore this variable and not take it any further in our investigation. Rnet, or R_n, has been introduced earlier in equation 1, from this, we can deduce that sensible heat is negligible as the air temperature at our chosen site, Hyytiälä, is so low throughout the whole year. This also applies for ground heat, which obviously can't retain any of the heat from its surrounding environment. So we consider these two variables to be negligibly small leaving us with the equation $R_n = LE$ and so these two variables, at this particular site, due to energy balance are considered the same. This is because as R_n rises so does LE. Due to this we decided to drop net radiation (R_n) from our investigation as it is too similar to LE.

The towers in Finland, which record the data we have used, are designed to measure NEE and not GPP as it can easily track and record the net exchange of carbon passing between the atmosphere and the forest. As NEE is directly observed it makes it a perfect choice to consider. GPP, on the other hand, may be more correlated with 'LE' but it is estimated based on some assumptions made on the rates of respiration. This in many ways is considered a flaw as the towers can't measure individual processes but can measure, with a high degree of accuracy, net fluxes.

We then turned our attention to respiration, its average value of correlation with repsect to LE was 0.483. As this value is so close to the 0.5 value we were limiting ourselves, so we could have possibly made an exception and considered it. However, due to the limited number of years the data for respiration was collected, as a group we agreed that we should drop the variable and not consider it anymore in our investigation.

Looking at table 2, we can conclude that, just by taking the strongest of the average correlations, the most strongly correlated variables are NEE, PAR, SWdown and GPP. We noticed that the variable GPP is strongly comparable to the process of photosynthesis and that NEE, PAR and SWdown are variables that are all linked to the process of photosynthesis. The reason for this is PAR is the wavelengths of light energy, from the sun, that the plant uses in order to photosynthesise with SWdown being the larger range of wavelengths containing

Table 2: Table of Correlations Between FLUXNET Variables and Latent Heat

Variable	1998	2001	2003	Average
Short Wave Radiation	0.801	0.854	0.798	0.818
Long Wave Radiation	0.314	0.338	0.402	0.351
Rainfall	-0.0474	-0.0468	-0.0154	-0.0365
Snowfall	-0.0278	-0.0168	-0.00468	-0.0164
Air Temperature	0.488	0.525	0.547	0.52
Wind	0.00673	0.0835	0.0539	0.0480
Surface Pressure	0.0305	0.0927	0.0277	0.0503
Humidity	0.268	0.310	0.381	0.320
Net Radiation	0.818	0.814	0.801	0.811
Sensible Heat	0.648	0.718	0.654	0.673
Gross Primary Productivity	0.883	N/A	N/A	0.883
Respiration	0.483	N/A	N/A	0.483
Net Ecosystem Exchange	-0.817	N/A	N/A	-0.817
Photosynthetically Active Radiation	0.801	N/A	N/A	0.801

PAR. NEE is the amount of carbon that is entering and leaving the system which corresponds to the carbon dioxide needed for photosynthesis to occur. So to conclude, we want to optimise the parameters in the equations that represent all plant processes, in JULES, in order to try and improve the representation of seasonality. Resulting from this information we concluded that photosynthesis is the most important process that governs the level of latent heat flux at our chosen site.

3.2 Computational Work in ADJULES

ADJULES proproved difficult to use at first, and required guidence from our project supervisor, but became fairly intuitive to use.

To improve the model fit for Latent Heat (LE) we improved the key parameters we identified in the equations associated with the process of photosynthesis. Equation 10 was the one we focused on.

$$E = \frac{\rho}{r_a + r_s}(Q_{sat}(T_*) - Q_1) \tag{10}$$

Where the symbols are given in our appendix. [19]

Our final values after the iterations are listed below, for a description of the parameters, refer to table 3.

Table 3: Table of the Parameters Investigated

Parameter	Explanation
q10_leaf	Leaf q10, an increase in rate in 10 degree increase in temperature
nl0	Top Leaf Nitrogen
α	Quantum Efficiency
f0	Stomatal Gradient
tlow	Lower Temperature For Photosynthesis
tupp	Upper Temperature For Photosynthesis
lai	Leaf Area Index
canht_ft	Height of Canopy
dqcrit	Critical Humidity Deficit

```
> params
           zw initial       final       perc z1==zlower z1==zupper
q10_leaf    1   2.000  2.69646059  34.823029          0          0
nl0_2       2   0.033  0.07899312  23.112122          0          0
alpha_2     3   0.080  0.07583862  -1.391764          0          0
f0_2        4   0.875  0.72353907 -30.910393          0          0
tlow_2      5 -10.000 -8.17611315   6.079623          0          0
tupp_2      6  26.000 34.31120915  33.244837          0          0
lai_2       7   4.000  2.73739105 -12.627352          0          0
canht_ft_2  8  16.380 38.30319549  43.846391          0          0
dqcrit_2    9   0.060  0.07674730   8.415728          0          0
```

The values listed on the left are the parameters that focused on vegetation processes rather than other factors, such as soils and hydrology. We optimised to specifically improve the seasonal representation in the way LE was modelled, as explained before in the Methodology.

After we had produced an optimised parameter set, we were able to compare a year long time series from the new optimised model to a time series of the initial model, and that of the observed data.

Figure 8: Optimised model for 2001

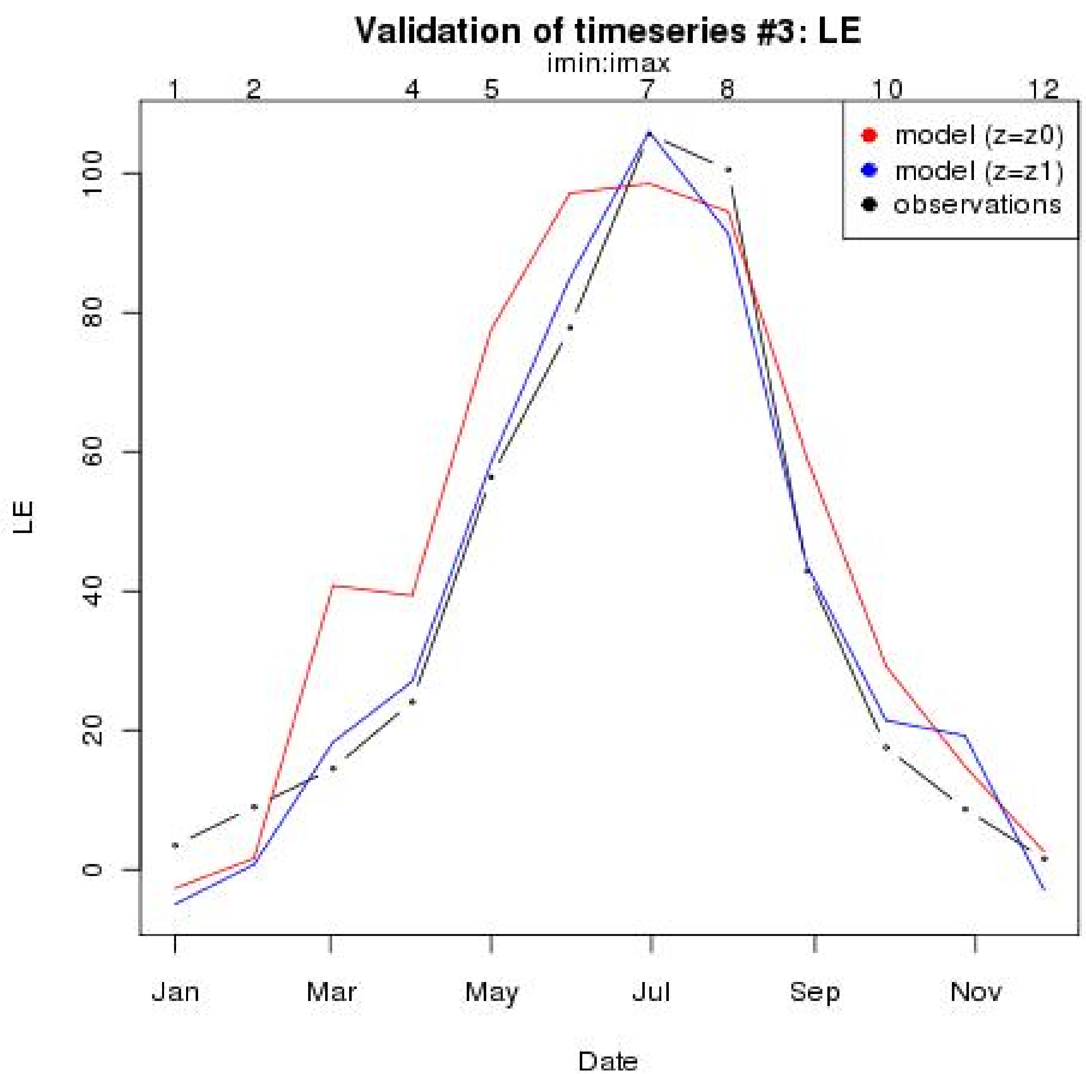


Figure 8 shows the results from the initial model (red) and from the optimised model (blue) for the year 2001. It is clear from figure 8 that the optimised model is a more suitable fit to the observed values. However, for the months January, February, November and December the optimised model is not as accurate as the initial model at representing the observed time series. This is because the program ADJULES optimises the parameters in JULES reducing the greatest differences between the initial model and the observed values. These parameters are constant. Therefore they will significantly improve the model in some areas but in other areas they may cause the model to not be as effective. The overall impact however is an optimised model which is clearly a more accurate representation of the time series of LE.

Figure 9: Error in 2001 model

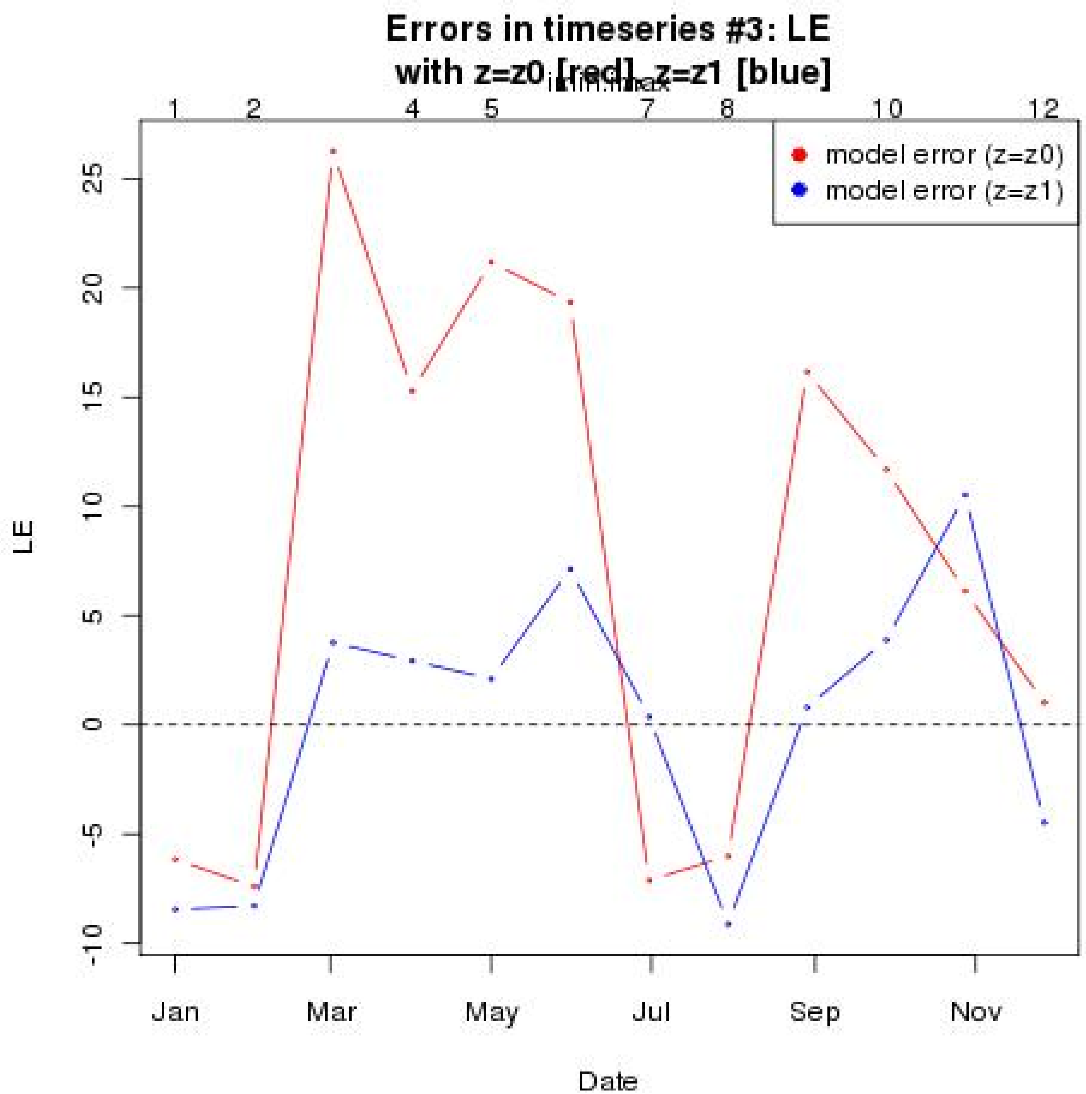


Figure 9 shows the errors in the models. We can see that the majority of the points from the optimised model have smaller errors than the initial model, as they are closer to figure 8. We can see that for some months the optimised model has greater errors than the initial model. The reason for this is explained in the previous paragraph.

In order to test the validity of the optimised parameters we ran our models for the years 1998 and 2003 which produced results shown in figures 10, 11, 12, 13.

Figure 10: Optimised model for 1998

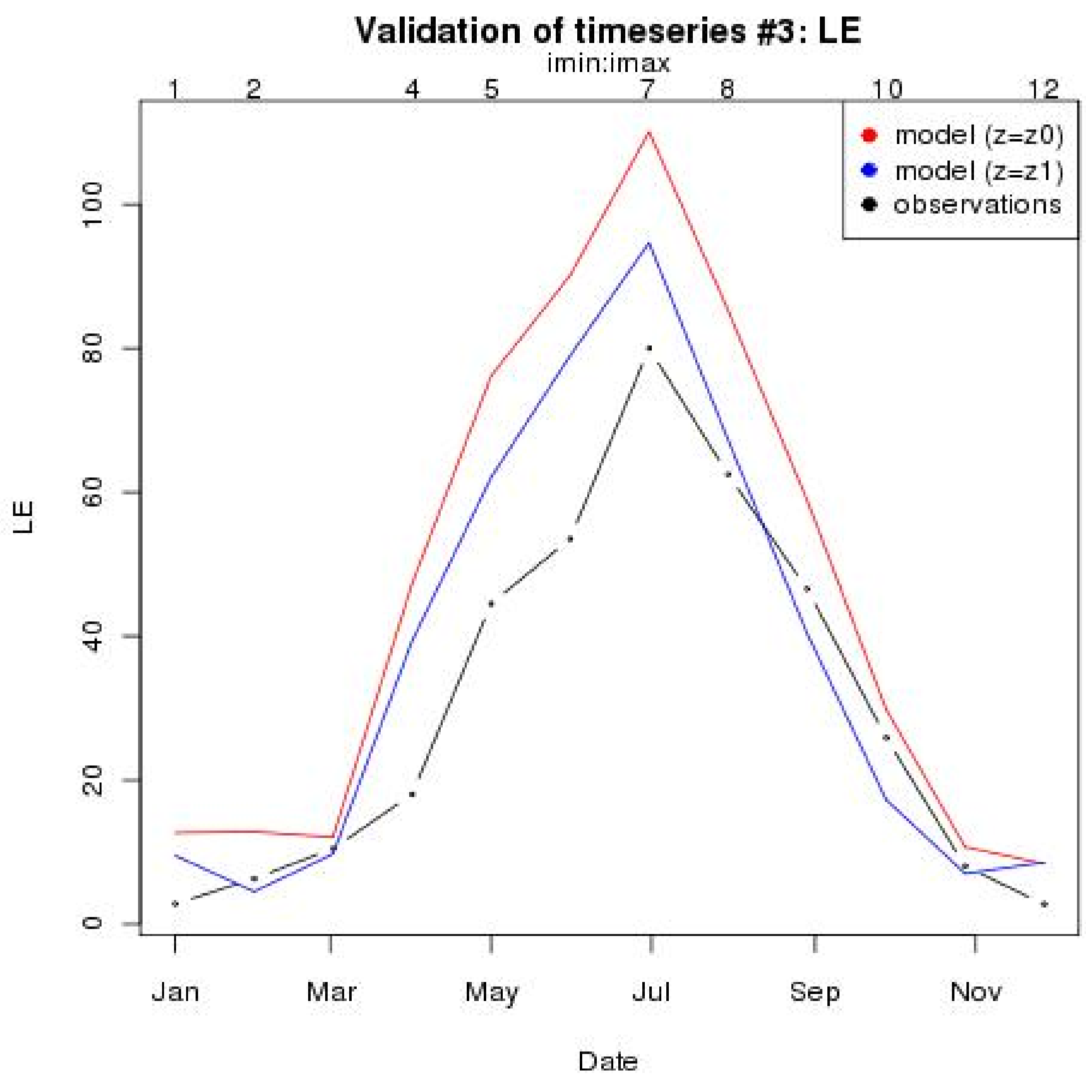


Figure 10 shows the results for the year 1998. We can see the optimised model is again a significantly better fit than the initial model. However, when comparing this with the 2001 data in figure 8 we observe the fit of the optimised model in 1998 does not appear as good as the fit of the optimised model in 2001. This is because we optimised the parameters for 2001 and as we mentioned before these are constant. Therefore the optimised model for 1998 may not be as accurate at representing the observed time series but the optimised parameters have given us a better model for 1998 than the initial model for 1998.

Figure 11: Error in 1998 model

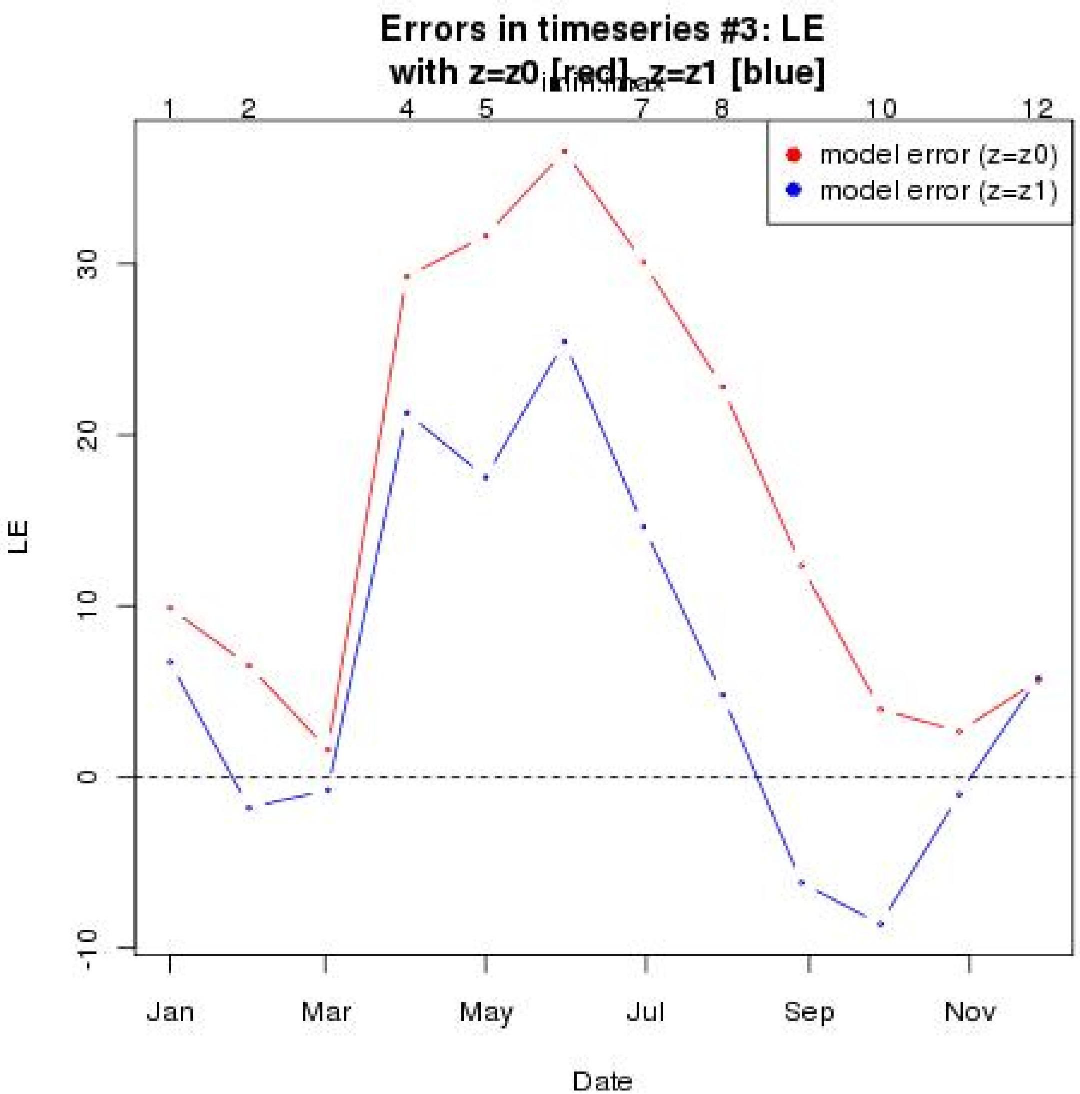


Figure 11 shows the errors of the initial and optimised models in 1998. They visually support the conclusions from figure 10.

Figure 12: Optimised model for 2003

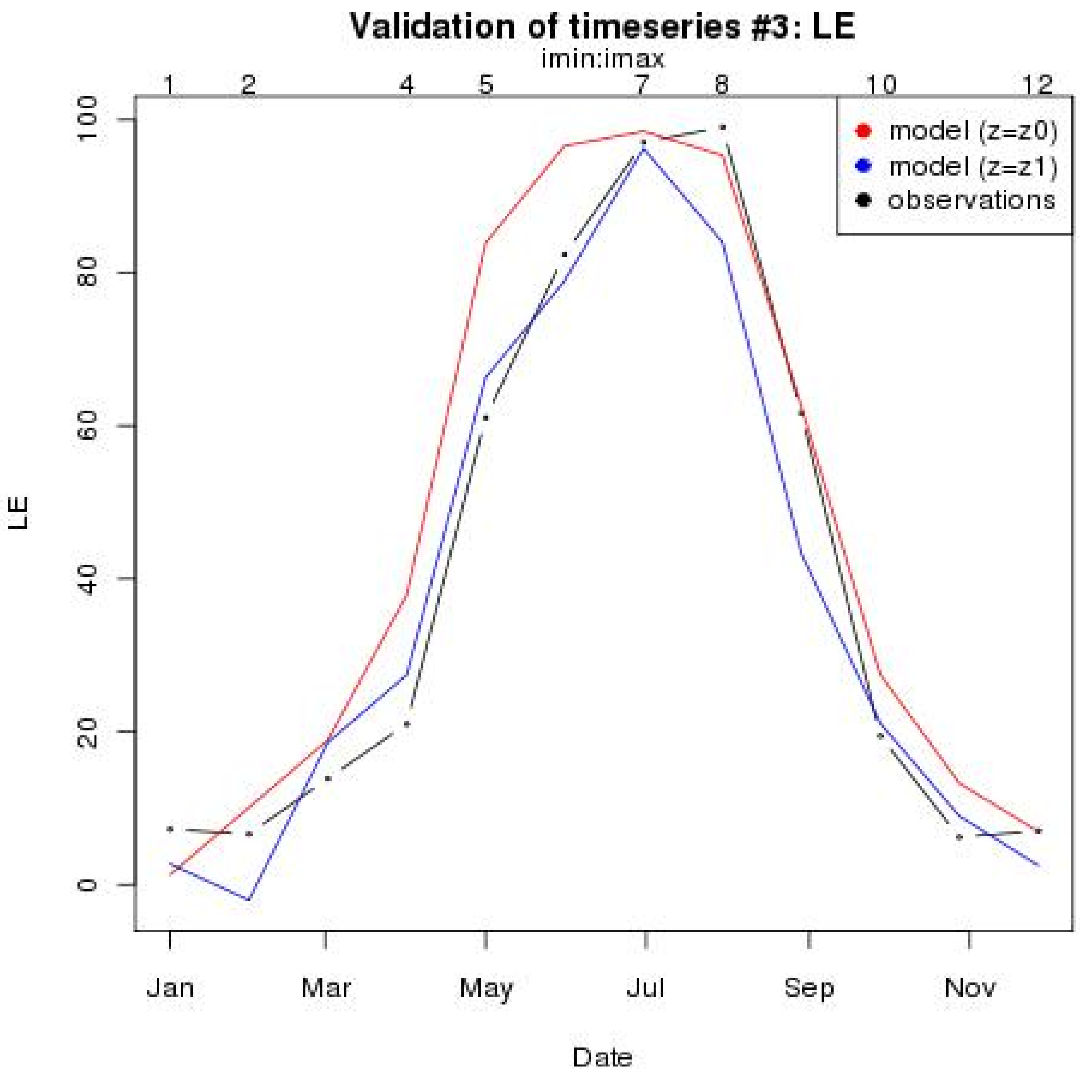
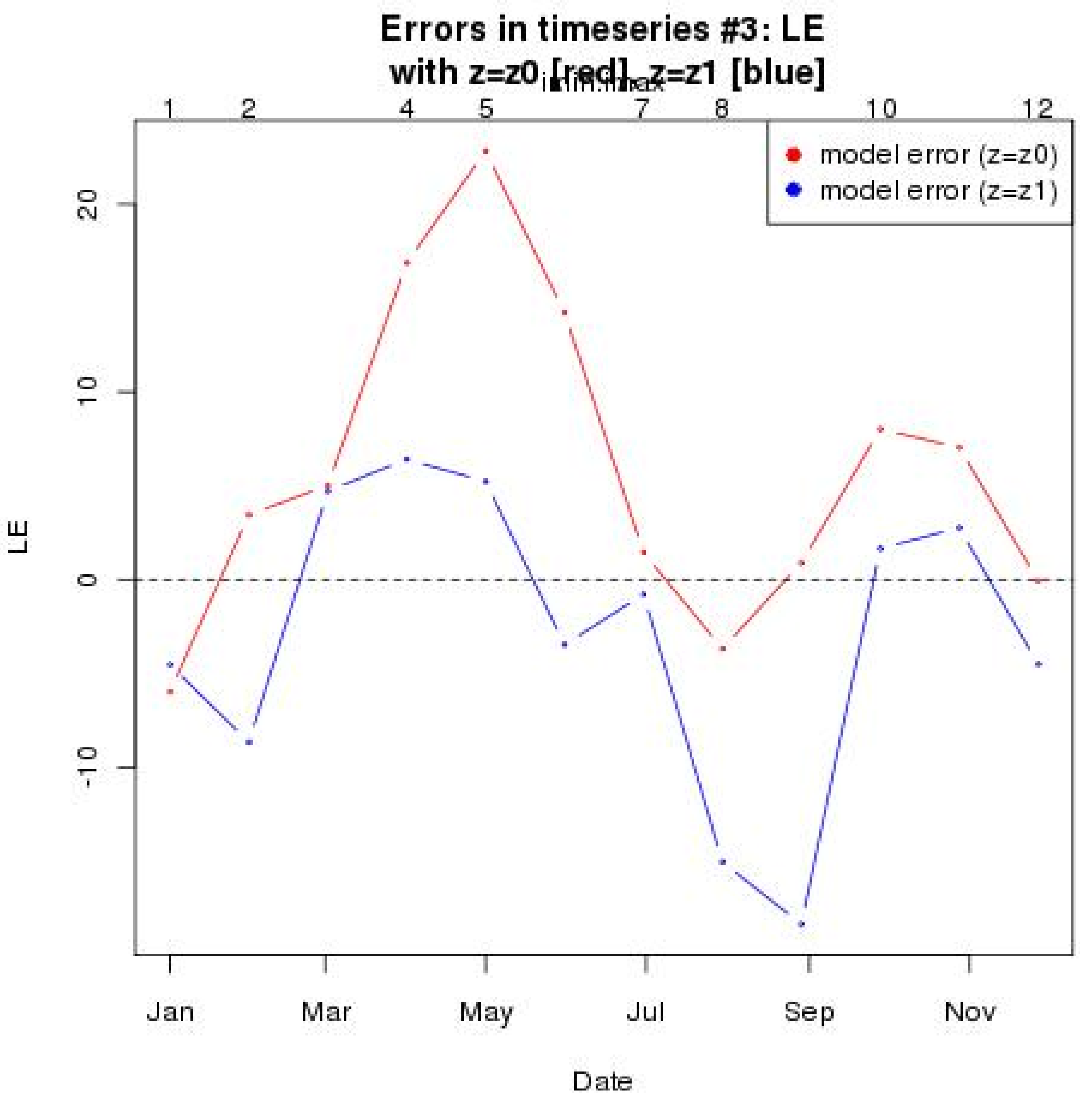


Figure 13 shows the initial and optimised models for 2003. Once more the optimised model gives a more accurate representation of the observed time series of LE than the initial model.
Figure 13 shows the errors for the initial and optimised models in 2003. Finally this visually confirms that the optimised model is a better fit than the initial model. The reasons for the exceptions where the initial model appears to be better are explained previously.

Figure 13: Error in 2003 model



4 Conclusion

4.1 Judgement of Overall Project Success

The aim of our project was to improve the representation of seasonality in JULES for our chosen site, Hyytiälä. As previously explained this corresponds to creating an improved model to more accurately represent the time series of LE. To do this, we optimised the parameters involved in the equations for the process of photosynthesis using the program ADJULES. Therefore, to determine if our project has succeeded in its original aims we need to ascertain whether our optimised model effectively represents the observed time series of LE and whether it is an improvement on any previously produced models. In the findings section we studied in detail the three years we decided to investigate at Hyytiälä, 1998, 2001 and 2003. For each year we graphically compared the observed time series of LE for that year with the time series given by the initial model and our optimised model. For all three years, the optimised model provided an extremely accurate representation of the observed time series of LE with only a few exceptions. Furthermore, from the graphs we concluded that our optimised model was better than the initial model at representing the observed time series of LE for all the years we studied. We can see that for all three years, in the time series graphs, the optimised model was closer to the observed time series than the initial model for the majority of each year. This is backed up by observing the 'Error in time series' graphs for each year. They give a clear visual representation that the optimised model has significantly lower errors for the majority of months for each year than the initial model. Finally, for the 2001 data we calculated the root mean square errors (RMSE's) for the differences between the initial model and the observed data and the differences between the optimised model and the observed data. For the initial model the RMSE was 10.04502 and for the optimised model the RMSE was 6.10896. A lower value of RMSE is better because it represents smaller errors between the model and the observed data. This gives further evidence that the optimised model produced a much more accurate representation of the observed time series of LE for each year than the initial model.

However, there were numerous cases when the initial model was better at representing the observed values of LE than our optimised model. We have explained why this might be the case in the findings section. But in conclusion our optimised model is not only effective at representing the observed time series of LE, it is also better than the initial model at this representation. Therefore we can confidently say we have improved the representation of seasonality in Jules for Hyytiälä for the three years we have studied. We have discussed that 1998 was a particularly cold year, 2003 had warm summer months and 2001's mean temperature was close to the mean temperature over all the years for which data was recorded. This means the years we studied give a fair representation of the range of temperatures of years that have occurred at Hyytiä'ä. This allows us to say that we have improved the representation of seasonality at Hyytiälä for the time that FLUXNET data has been recorded there.

The Blyth et al 2010 paper contains research evaluating the JULES land surface model energy fluxes at numerous FLUXNET sites including Hyytiälä. In this paper they carried out very similar research to our project. They used JULES to model the time series of LE and compared it to the observed time series at Hyytiälä. The graph they produced in Blyth 2010, figure 2, was very similar to our figure 8 with both observed time series having similar shapes. Our initial model, in figure 8, also has a similar shape to the Jules model produced in the Blyth paper. They both fit the observed time series well for late summer, autumn and early winter months but are well above the observed time series for late winter and spring months. This implies that JULES predicts an earlier spring than occurs at Hyytiälä.

The comments made in the Blyth 2010 paper, table 2, were that the model follows the seasonal cycle of the observed time series but the modelled time series is too low in winter and too high in summer. The Blyth 2011 paper has similar results stating that JULES models an early increase in LE at the Hyytiälä site. This corresponds to our findings. We can see from our optimised model that this problem has been significantly improved for the three years we studied. The optimised model is closer to the observed time series than the initial model fo rspring and early summer months for all three years. In fact from analysis of all three years we can see that in general our optimised model improves the representation of the observed time series best for the months April, May and June (i.e. spring and early summer).

Using ADJULES to optimise the parameters involved in the equations for the process of photosynthesis has significantly improved the issue arising from Blyth's research. Furthermore the use of ADJULES to try and improve the representation of seasonality at Hyytiälä has never been carried out before. This means we have made a significant contribution to the existing literature on our site of research.

From carrying out this study we also learnt some interesting information about how the real Hyytiälä forest operates. For the particular vegetation at this site, Evergreen needle leaf trees, we discovered that latent heat flux is very tightly coupled with the process of photosynthesis and with solar radiation. It is also strongly linked with the surrounding air temperature. We also ascertained that latent heat flux is not related to the meteorological variables rainfall, snow, wind and ground heat. This information notifies us of the natural processes and relationships that occur in the vegetation at Hyytiälä.

4.2 Analysis On Our Findings

From this piece of work we can come to the conclusion that, throughout the course of our project we have successfuly produced an improved model. We remind ourselves to ask, however, whether these conclusions are sound and whether we have followed logical steps to reach our findings. Everything we have used has come from well-researched sources and is backed up with evidence in the form of talking to our project supervisors and previously written papers in the same subject area. This in itself provides a high degree of reliability, as we know that the scientific community does not publish such papers without significant evidence and accurate information.

It also helped that both of our project leaders are involved heavily in this area of study. Although not much research has been done into the site we were looking at (comparatively with other sites), we were able to look at information around the world to compare our project with other studies which gave us a good indication of how the model should behave. It helped that, as a group, we had a good knowledge of how R worked. This was our main tool in producing the results we have obtained. We also developed skills in LINUX, JULES and ADJULES and now all feel more confident with using these programs.

Having this experience and knowledge meant that in our spare time we could work on the project without the supervision of our project coordinators, thus speeding up the process of getting together our data. Oue project leaders then had more time so they could review the work we had done and help to point us in the right direction if anything was slightly amiss, making sure all of our work was achieved to a high and accurate standard.

One possible area for improvement could have been our communication as a group, however we did well to organise regular group meetings twice a week, occasionally more if need be. Sometimes though, not all of the group could attend due to other commitments. This made it difficult to ensure what needed to be done or improved upon was achieved.

We tackled this to some extent by writing up regular minutes of each meeting and posting them on our facebook group to ensure everyone was updated. Perhaps an improvement in this area could have been made had we elected one person to be dedicated to this task. Then a secondary meeting could occur to fill these absentees in. However, we decided not to take this approach as it would be extremely time consuming for at least one member of the group and we all have other dedications and deadlines to pursue outside this project.

4.3 Challenges & Developments

It is important to note that this was a group project and therefore we should evaluate the overall effectiveness of the group. The first and possibly most significant hurdle could well have been that of communication between our eight person group. It appears we managed to avoid any substantial communication issues by exchanging mobile numbers, creating a Facebook group and by arranging another group meeting on Tuesday evenings outside of our meetings with our project supervisors. Some issues however did become a challenge, like that of time management. For example, in our critical path analysis we estimated that the majority of the Jules and R programming would take approximately one week per set of iterations. Our original plan was to work in tandem with our project supervisors so that we could better understand the process of JULES and ADJULES, however, due time pressures, and the complexity of the work, they had to take a more active role, such as parts of scripting for ADJULES. Despite this however, we have managed to get the project in on time, so our time management must be considered to be a success.

Another potential issue was that of our different computational and biological backgrounds, with some of us having very limited knowledge of one or the other. To successfully overcome this obstacle, we had to dovetail throughout the project with one team focusing on the programming and the other on the biological and site background research. With this done, we came together to write up project. This variability actually proved to be useful as the size of the project dictated the requirement to spread the workload evenly if we were to complete it in time.

One of our most significant problems was the background research on the Hyytiälä site, or lack of it. Due to the sometimes limited quantities of data on the site we were not capable of using the years we had originally chosen, and when we attempted to do background research on the site there were far fewer papers than we anticipated. However, part of the reason we chose this site was because of how it was not so well documented, meaning that our research may actually prove useful for the academic community.

Thus, we would conclude that as a team we managed to successfully negotiate the generic and technical issues that we came across allowing us to compete the project in a timely and accurate manner.

During the optimisation part of this project we came across a number of problems, with data, time management and technical issues. Some of these technical issues included coding with minor errors, incorrect formatting or simple human errors, such as ensuring that the programme knew which directory to read from throughout the process. Although these were all only minor setbacks it did increase the time taken to complete this section of the project considerably.

To make up for this we ensured that other aspects of the project, like writing up the report, were still going on whilst one or two people solved any issues. This meant that all of our data sorting, graph plotting and analysis still finished on time and the project itself was not delayed.

4.4 Future Directions

Our project was a specific investigation into a small area of the vast field of land surface modelling. There are 411 active FLUXNET sites around the world, all of which provide continuous data on numerous factors of water, carbon and heat fluxes amongst others. Many of these sites have up to ten years of data, such as the Harvard site. We have examined a particular FLUXNET site for three years and only looked at certain parameters. Therefore we have only scraped the surface on the level of data available and hence the level of further research that could be carried out.

In terms of Hyytiälä, with extra time and resources we could have optimised more parameters to try and improve our optimised model. We could also have looked at more than three years to see if our optimised parameters improved the model for all the data recorded at Hyytiälä. We specifically looked at plant processes effecting LE in this location in our project. In the future, research could be carried out on the relationship between other variables and the processes that affect them.

On a more global scale a similar investigation could be performed at other FLUXNET sites with differing vegetation types and climates. A comparison with our findings would yield interesting results on how LE varies in these differing conditions. We looked at a site where there was only one type of vegetation. If an identical process was executed at a site where there was a mix of vegetation types it would give an insight into how the interaction between vegetation affects levels of LE. Furthermore, we know that JULES can be run globally. It can run a simulation for the time series of LE for every one degree by one degree box over land. However ADJULES can only be run at specific sites, where there are FLUXNET towers. This is because ADJULES has to compare with data observations recorded at the towers. Therefore in the future we could use the optimised parameters we obtained from ADJULES at Hyytiälä and apply them to JULES to run a global simulation of the time series of LE. We can then investigate whether this would improve seasonality on a global scale. If this was successful it would have crucial implications for the global hydrologic and carbon cycles [18]. (Blyth 2010 & 2011)

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5 Appendices

Table 4: Explanation of Symbols used in this Report

Symbol	Units	Definition
Q_1	$kgkg^{-1}$	specific humidity at the reference atmospheric level
$Q_{sat}T$	$kgkg^{-1}$	saturated specific humidity at the temperature T
r_a	sm^{-1}	aerodynamic resistance
r_{acan}	sm^{-1}	aerodynamic resistance between the surface canopy 4 of vegetation and the underlying soil
r_s	sm^{-1}	stomatal or surface moisture resistance
T_k	K	temperature of the k-th snow layer
T_{s1}	K	temperature of the first soil level