**4. Discussion**

In this chapter, the results and the methodology will be discussed. First, the results and their limitations for the three research questions will be discussed, followed by a more general discussion of challenges and limitations of the approach presented in this thesis.

***4.1 Dataset validation: comparing LAIre to LAI3g***

*Comparing raw LAI data*

The high correlation coefficients between raw LAIre and LAI3g data suggests that the model created by Stöckli et al. (2011) produces LAI values similar to remotely sensed data and can therefore be used for further analysis. Variations between the two datasets can be explained mainly due to the slightly different values they represent. In the LAIre dataset, a bimonthly value represents a mean of daily, modelled LAI values. In the LAI3g dataset on the other hand, a bimonthly value represents the mean of an unspecified number of acquisitions for each 15-day period. Furthermore, atmospheric effects and the saturation of values at higher LAI in densely vegetated areas can play a role (Zhao et al. 2012). This is particularly evident when looking at a scatterplot between two datasets (Fig X1) where a group of pixels in the tropics show a bigger LAI in the LAIre dataset whereas the LAI3g shows a saturation effect and therefore smaller LAI values. The resampling of the LAI3g also lead to differences in coastal areas due to it being a mix of water and land pixels which can also be seen in the scatterplot in Fig. X1.

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| Macintosh HD:Users:davidschenkel:Dropbox:Masterarbeit:geo511:writing:figures:scatterplot.png |
| **Fig. X1**: Scatterplot of raw values from LAI3g and LAIre for the period of September 1. – 15. 1985. Green: Differences due to resampling of LAI3g dataset (coastal areas). Red: Saturation effect of LAI3g in the tropics where LAIre estimates higher values. |

*Comparing LSP parameters*

Even though the very low correlation coefficients for all extracted LSP parameters might suggest that there is little agreement between the two datasets, a visual analysis of where the differences are show a different picture. The two datasets agree well in regions where there is one distinct growing season per year, for example in high and moderate northern latitudes, as proven by very high correlation coefficients for the SOS between 45 to 90 degrees northern latitude. For those regions, small differences of around 15 to 30 days are expected due to the temporal resolution of the datasets of 15 days.

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| Macintosh HD:Users:davidschenkel:Dropbox:Masterarbeit:geo511:writing:figures:EOS_extraction_variability.png |
| **Fig. X2**: Vulnerability of EOS-date extraction to small changes in LAI-value of SOS/EOS due to the gentler slope during senescence |

The low correlation coefficients for EOS suggest that more complex factors are at play in autumn. The main factor leading to extremely low correlation coefficients is that the LAIre does not show one clear trend towards over- or underestimating the EOS, but rather shows a lot of variability in both directions. However, there are some factors specific to the EOS, which also add to the variability and the bigger absolute differences observed. On the one hand, climatic factors such as temperature have been shown to influence autumn phenology several months in advance of actual EOS (Jeong et al. 2011), which is not taken into account in the modelled LAIre. On the other hand, the extraction of the EOS itself is subject to much more variability than that of the SOS because the LAI profile usually has a steep slope during SOS, but a much gentler slope during EOS. This makes the EOS-extraction much more susceptible to small differences in EOS-value leading to big differences in extracting the date of EOS (see Figure X2).

Moderate and high southern latitudes show more variability in extracted LSP parameters which corresponds to prior findings (White et al. 2009; Garonna et al. 2014) and should therefore be used with caution when trying to verify the modelled LAIre. Growing patterns and the LSP extraction methods mainly explain the differences in those regions. In tropical regions for example, where there is no clear start and end of season, small differences in data can lead to LSP shifts of half a year. These differences arise from a combination of tropical growing season patterns and the LSP extraction methods and do not necessarily indicate a disagreement between the two datasets.

The effect of different LSP extraction methods can also be seen when comparing the results from the MI method to the MP method. The correlation coefficients for the LSP parameters extracted with the MI method are only half as high as correlation coefficients for the MP method. This corresponds to prior research where it was found that the MI method shows more variability from year to year, as compared to the more stable MP method (Garonna et al. 2014). This would also suggest that the MP method is more useful when trying to validate a dataset.

*Trend analysis 1982 – 2011*

The trend analysis for both dataset shows similar regional patterns for all three LSP parameters. The decadal change rates for the LAI3g dataset are however much stronger compared to the LAIre. This is particularly true for densely populated areas in China, where the LAI3g shows a strong shift in SOS towards an earlier day of the year, whereas the LAIre shows almost no change in those areas over the last 30 years. This difference in measured data and modelled data suggests that non-climatic factors might be responsible for the observed change. Improved agricultural productivity to support economic and population growth (Cao & Birchenall 2013) most likely caused these particular shifts, which the LAIre is unable to model.

A big difference in the two datasets can also be seen in the ecotone between savannah and desert in the Sahel. The big differences in GSL are due to different trends observed for SOS and EOS in the two datasets. The LAIre shows a much later onset of SOS than the LAI3g, which leads to a shortening of the GSL in the LAIre data. The LAI3g however shows a trend towards slightly later onset of EOS, leading to an increase of the GSL. The satellite based observations and matching field observations that plant activity in the Sahel have increased in the last 30 years were already described by Dardel et al. (2014) and others (de Jong et al. 2011; Anyamba & Tucker 2005). The difference in modelled and remotely sensed observations most likely arises from re-greening of the Sahel in the past 30 years and therefore the changes in land-cover type (Foody 2001; Dardel et al. 2014; Mishra et al. 2015) which are not taken into account in the modelled LAIre. This would suggest that dynamic land cover estimations are needed to model the changes in ecotones, particularly along deserts where changes in LSP are necessitated by changes in land cover type.

*Limitations due to the dependence on MODIS LAI*

While the results from the comparison of the two LAI products suggest a generally good agreement of modelled data to remotely sensed data, one has to keep in mind that both the LAI3g and LAIre are connected to the Collection 5 Terra MODIS LAI product and therefore not completely independent from each other. In the case of the LAI3g, MODIS LAI from 2000 to 2009 was used to train the neural network algorithm to connect NDVI3g data to MODIS LAI data (Zhu et al. 2013). To produce the LAIre, MODIS LAI was used for data assimilation (Stöckli et al. 2011). A verification of the modelled LAIre with a MODIS-independent product such as the LAI CYCLOPES global product (Baret et al. 2007) would be desirable, once similarly long time series of around 20 to 30 years like the LAI3g are available. For the time being, the LAI3g is, however, the only reliable long-term LAI dataset available and therefore more suited for a verification of the modelled dataset.

Beside the problem of interdependence of the two products, it is also worth looking at how well the products correspond to actual field data. Fang et al. (2012) compared both, MODIS and CYCLOPES LAI to in-field measurements. They found that while both products achieve good and very similar results, the uncertainties associated with both product are still outside of the requirements for “satellite based data products for climate” by the World Meteorological Organization (GCOS 2011). This is an important limitation at the moment since the LAI could one day be a key measure to connect remotely sensed data directly to biophysical parameters (Fernandes et al. 2014).

***4.2 Climatic Controls***

*Yearly Dominating Controls*

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| Macintosh HD:Users:davidschenkel:Dropbox:Masterarbeit:geo511:writing:figures:discussion:unique_dominating_controls.png |
| **Fig X3:** Map showing the number of dominating controls from 1982 – 2011. Areas which show 2 dominating controls correspond to ecotones |

The results for yearly dominating controls mirror those of Jolly et al. (2005). In contrast to Jolly, no areas of “no seasonal constraints” in the tropics were defined, instead those areas appear as radiation controlled since photoperiod is the limiting factor. The map of unique dominating factors in the last 30 years (Fig X3) not only shows where more than one control poses limitations to plant growth, it also coincides with ecotones (Garonna 2015, submitted). This finding could potentially be used to study long-term changes in global ecotones by analysing changes in their spatial extent over time.

Visible and large-scale change of dominating control can be seen in South America where parts of Brazil change from a radiation-control dominated environment in the 1980s to a moisture-controlled environment in the 2000s. This change coincides with several strong drought events in Brazil in the years 2000 – 2010 (Anderson et al. 2015). Since drought events are extreme weather phenomena, the change in dominance should not be overstated just yet, since it is only really visible from 2000 onwards. Further statistical analysis and longer time series are needed to assess long-term change in climatic controls in this region, independent of extreme events.

Small changes in dominating controls run mainly along borders of areas with different domination controls and vary by year without a clear trend in one direction. An interesting exception is northern Europe, which, even though it is temperature dominated in most years, shows some years (1989/1990, 2000 and 2005) where the radiation control becomes the dominating factor over a large area. A possible explanation of these outliers could be the North Atlantic Oscillation (NAO), which shows particularly positive NOA-index values for the affected years (Gouveia et al. 2008). However, interactions of ocean currents and LSP are very complex and further research is needed to find and confirm links between the two.

*Quarterly Trends for Climatic Controls*

To extend Jolly’s analysis of how climatic controls vary within a single year, a trend analysis for each quarter of the year gives an insight into how the intra-annual controls change over the years. The radiation control will not be discussed in detail in this section since it showed no significant change over the last 30 years. This is due to the dependence on day-length, which has not changed considerably in the last 30 years.

*Temperature*

As expected based on the latest report from the IPCC (IPCC 2014), global rising temperatures lead to a global decrease of influence for the temperature control factor. Because mainly the northern hemisphere is affected by a dominating temperature control, this is also where the change is most visible. Looking at the change from quarter to quarter, a south to north pattern can be observed starting in the Middle East in the first quarter and moving north towards northern Europe in the third quarter. This stratified change in temperature control happens because the control factor only changes when temperatures are within the thresholds of the GSI-factor, roughly around -2 to 5 degrees centigrade, depending on PFT. If temperatures change outside of this window of constraint, it will not be visible in this analysis. Hence, the change of temperature control coincides more or less with the 0-degree-centigrade line as it travels north in spring.

Even though a decrease in influence of temperature was expected, the rate of change particularly in Iran in the first quarter of over 20% per decade is surprisingly large, implying a complete change in dominating factors within a matter decades. This is particularly interesting since other studies found no significant mean, minimum and maximum temperature change for the first quarter of the year from 1960 to 2010 (Ghasemi 2015; Saboohi et al. 2012). Ghasemi mentions though that a steeper increase starting from the 1990s is expected. It has yet to be proven however if the change observed here is due to Ghasemi’s expected change, if it is an artefact of the ERA-Interim dataset, or if it is a result of severe droughts in Iran in the early 2000s that lead to depleting rivers and lakes (Agrawala et al. 2001), therefore changing land cover types dramatically.

It is also worth looking at the areas where temperature control has increased, as is the case in the second quarter in eastern Australia and western Canada. Jacobs et al. (2013) showed that eastern Australia did not show a significant annual warming trend from 1979 to 2010 which makes a slight increase in temperature control intra-annually plausible. Additionally, they found a cooling trend in eastern Australian during La Niña episodes. However, their analysis is also based on ERA Interim data, like the climatic control data in the LAIre dataset, and should therefore be verified with an independent source.

For western Canada, the situation is very different. The literature unanimously shows an increase in mean, minimum and maximum temperatures for all seasons in this period (Bonsal & Prowse 2003; Beaubien & Freeland 2000; BCMoWLAP 2002), making an actual increase in temperature limitation questionable. Closer inspection of the bimonthly climatic data from which the quarterly trends are aggregated shows that an increase in temperature control only shows up in 2 out of the 6 relevant 15-day periods from April to June, each in a slightly different, adjacent region. This increase in temperature control is therefore most likely an artefact of the interpolation of the ERA-Interim dataset and its aggregation into quarterly means and does not correspond to actual conditions on the ground.

*Moisture*

The moisture control trends show a higher global variability than trends in temperature limitation, but many regions show a strong increase in moisture control of up to 10% per decade. As Matsoukas et al. (2011) note, part of the increase in control is due to the ERA Interim data on which the climatic controls are based, showing a faster rise in air temperature T than the rise in dew point temperature Td, leading to increasing estimates for VPD. This would suggest that at least some of the observed increase in VPD control might not correspond to actual changes in VPD on the ground. The variations and very strong increases in VPD control in some regions do suggest though that changes in VPD are not only due to a general increase in the difference of T to Td from the climatic data. This means other factors are at play and a more in-depth analysis of the trends found here is indeed justified.

A lot of the areas showing a strong increase in moisture control are semi-arid and arid regions, which are absolutely dominated by moisture control over most of the year. Increases in moisture-control can only happen in the winter months, where the moisture limitation is not absolute, meaning the moisture control factor is not exactly 0 in that time. While this change will not have any effect on LSP since there is no vegetation, it is none the less an indicator of the further drying out of semi-arid areas globally. No change is observed in the summer months, when moisture is already as limiting as it can get.

Interesting cases are the regions that are not dominated by moisture control but show an increase in moisture limitation. This is the case in most of Europe for example, which shows an increase in moisture control particularly during the second quarter of the year, when plant growth rates are at a peak. Since this does not coincide with any change in annual dominating controls over the past 30 years, no visible effect on LSP is expected yet. However, if change rates remain at the current 5% per decade, an impact of moisture limitation on LSP could become noticeable in the coming decades.

Strong increases in moisture control can also be found in South America over all four quarters. This increase is likely amplified by several major drought events between the years 2000 and 2010 (Magalhães & Martins 2011). The impact of this change in control does not correlate with LAI measurements however (Anderson et al. 2015), suggesting that other biophysical parameters influence phenology more than evaporative stress. Due to the droughts in the early 2000s, doing an analysis of trend breaks would be particularly useful here to assess the influence of short-term trends of climatic controls on LSP.

The decrease of moisture control in southern Africa and north-eastern Australia, which are dominated by moisture control over all 30 years, are also worth discussing. The effective decrease of VPD, or increase in available moisture, has been analysed in prior research for both regions based on modelled as well as remotely sensed data (Dorigo et al. 2012; Chen et al. 2014). While Dorigo et al. point out that precipitation is the main driver for the increase southern African soil moisture, there is no clear consensus yet how precipitation and soil moisture influence each other in this region (Dorigo et al. 2012; Cook & Pau 2013) or how and how strongly ocean current anomalies such as the ENSO influence southern African precipitation and soil moisture (Reason & Jagadheesha 2005). More research is needed to understand these interactions and to understand their relevance for future trends in LSP.

*Limitations of the climatic control model (extended GSI)*

Apart from the limitations regarding regional differences which were discussed before, the model used for the climatic controls as well as the controls themselves have some limitations, which will be discussed here. Firstly, the threshold based Growing Season Index does not work equally well for all land cover types, as Jolly et al. (2005) note. Stöckli et al. (2011) tried to extend the model by setting different thresholds for temperature, VPD and radiation depending on the mix of Plant Functional Types (PFT) present in each pixel. While this adaption definitely allows for a more precise analysis of climatic controls on a global scale, the PFTs used by Stöckli do not change over time. This introduces uncertainties in areas where a significant change of land cover has occurred over the observed 30-year period. A more adaptive algorithm to deal with land cover changes during the observation period would therefore be required to more accurately extract the climatic control factors.

A second uncertainty stems from unknown behaviour of most plants in a changing climate. While a linear threshold model as used by Jolly might be adequate for current conditions, it has yet to be seen how well it works when temperature becomes less of a driver and moisture becomes a more important global limiting factor. Adding to that is the unknown evolutionary adaptive nature of plants in a changing climate. Studies for individual plants have shown rapid evolution in some species to cope with a changing environment (Franks et al. 2007), however very little is known about how most plants of whole ecosystems react to long-term changes in limiting climatic controls.

Looking at the three climatic factors used for this analysis, temperature and radiation can be considered direct measures of a limiting factor, while VPD cannot. As Jolly et al. (2005) note, VPD is used because it can be calculated easily and continuously. They also remark however that plant-climate interactions influencing VPD are complicated and ask appropriately: “does VPD influence phenology or does phenology influence VPD?”. A better understanding of the complex nature of the VPD in the climate-LSP model is needed to really understand the impact of the changes observed in this thesis, and how they might affect LSP in the future.

* 1. ***Climatic Controls compared to Phenology***

In this chapter, results from all three research questions are combined to analyse the impact of changes in climatic controls in the 30 days prior to start and end of season.

*Dominating Controls at SOS and EOS*

When comparing dominating controls at start and end of season, big differences are visible in the spatial distribution of the controls. During SOS the pattern is very similar to those found in yearly dominating controls (section 3.2.1). This is in strong contrast to the dominating controls at EOS, which show a completely different pattern, particularly for the northern hemisphere. Differences can also be found when looking at the temporal variability of dominating controls during SOS and EOS. For the SOS, the changes over time are small and are located at the borders of different dominating controls. For EOS on the other hand, large scale changes in dominance can be seen from year to year particularly for the northern hemisphere, but also in southern Africa and South America.

*Start of Season in the northern hemisphere*

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| Macintosh HD:Users:davidschenkel:Dropbox:Masterarbeit:geo511:writing:figures:NHEM_dominating_tempchange.png |
| **Fig. X4: C**omparison of dominating controls at SOS (a), changes in the temperature limitation during the second quarter of the year (b) and decadal change of SOS from 1982 – 2011 (c) |

For the Start of Season in the northern hemisphere, the temperature domination coupled with decrease of temperature control observed in the second quarter results in an earlier SOS (see section 4.2 and 4.1 respectively). This is a strong indication that temperature was and still is the main driver for plant growth for the northern hemisphere, as has been the general consensus in the literature (Jeong et al. 2011; Badeck et al. 2004). This is further confirmed by the trend analysis of temperature control during Start of Season. It shows very little change during start of season for most of the northern hemisphere, implying that the SOS and minimum temperature change at similar rates (Fig X5) since minimum temperature directly drives SOS. Exceptions are Scandinavia, Britain, Central Asia as well as China, where influence of temperature control is getting smaller during SOS. This would imply other processes, either climatic or anthropogenic, started having an influence on SOS during the last 30 years in those regions.

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| **Fig. X5:** Shift in temperature control (a) and LAI (b) for first half of the year for 1982 and 2011 towards an earlier date in the northern hemisphere |

With rising temperatures and earlier SOS onset, other factors might start having a stronger impact on the Start of Season. As expected, the trend analysis during SOS showed that radiation is an increasingly limiting factor since the SOS moves towards earlier dates and therefore to days with less daylight. Due to the rising importance of the moisture control in spring in the northern hemisphere as seen in section 4.2, it could be expected to see an increase in moisture control at Start of Season as well. This was however not the case in the trend analysis. With the earlier onset of SOS, the moisture control factor does neither increase nor decrease in the 30 days prior to SOS. This counterintuitive finding is important since it shows the consequence of connecting LSP to climatic controls, rather than just looking at climatic factors by quarter as done in section 4.2.

*Start of season in the Southern Hemisphere*

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| Macintosh HD:Users:davidschenkel:Dropbox:Masterarbeit:geo511:writing:figures:SHEM_dominating_tempchange.png |
| **Fig. X6:** Comparison of dominating controls at SOS (a), changes in moisture limitation in the 3rd quarter (b) and decadal change of SOS from 1982 – 2011 (c) for South America and Africa |

For South America, a similar analysis at SOS as in the northern hemisphere can be done. By looking at a combination of dominating controls at SOS, change of moisture in the third and fourth quarter of the year and the shift in SOS during that time (Fig. X6), one can find that the shift in SOS towards a later date might be explained by the change in moisture limitation. Moisture is the dominating factor for the affected region and shows an increase in control over the 30 years analysed. With this increase in moisture limitation, a later onset of the growing season is observed. This dependence on moisture has already been shown for seasonal behaviour for certain forest types in Brazil (Funch et al. 2002) but not in a long-range and large-scale trend analysis such as this thesis. Changes in moisture availability and LSP due to large scale logging in the Brazilian amazon rain forest which were found based on MODIS time series analysis (Koltunov et al. 2009) could not be seen in the analysis on this larger spatial and temporal scale. While some change in moisture in the Amazonian rainforest can be seen, a large part of the major increase in moisture control is outside of the rainforest and its causes are therefore likely not directly connected to logging. The changes in LSP caused by logging themselves are most likely hidden since the LAIre does not take into account changes in land cover as discussed in section 4.1.

A similar situation to Brazil can be seen in the south-eastern tip of Africa, where the SOS also shows a trend towards a later date of year in the moisture-control dominated area. While the changes in moisture control observed during the third and fourth quarter of the year (see Fig. X5) are very small, the trend analysis for the 30-day period prior to SOS shows a clear increase in moisture while temperature and light controls go down due to the delay of SOS. However, in both South America and south-eastern Africa it cannot be clearly determined if moisture is the driving force behind the change, or if the change in moisture is influence by the change of SOS (see discussion of VPD in previous section and Jolly et al. 2005).

*End of Season in the Northern Hemisphere*

Due to inter-annual variability of dominating controls during the End of Season, analysing the impact of the dominant climatic control in that period is not as straightforward as for Start of Season. Because of the frequent changes in dominating control from year to year, connecting the changes of limiting climatic controls to changes in date of EOS cannot be done. For the northern hemisphere in particular, the high variability of dominating controls over the years could be an indication that the climatic factors influencing the End of Season are more complicated and multi-facetted than the temperature dominated Start of Season.

However, it could also be an indication that the main drivers for End of Season happen earlier than the 1-month period studied in this thesis. For the northern hemisphere this seems to be the case according to Jeong et al. (2011) who found that temperature related effects initiating the End of Season can occur up to 4 months before actual EOS. This finding is supported by the analysis of individual trends of climatic controls during EOS. A strong increase in moisture control can be seen for most of the northern hemisphere, which goes against the finding that EOS shows a delay for much of the northern hemisphere particularly in the past 10 years. Therefore it must be concluded that changes of control just prior to EOS did not affect the date of EOS during the past 30 years.

Nonetheless, the big variations in dominating climatic control factors during EOS could be the key to help explain why the rate of delay of EOS has increased in recent years in Europe, while the rate of earlier onset of SOS has remained more or less stable (Jeong et al. 2011; Garonna et al. 2014). The high temporal and spatial variability in dominating controls during EOS also indicate that a more regional analysis based on regional climate models is needed to understand the exact effects on plant senescence. Also, the large-scale increase in moisture control for the northern hemisphere might become an important control for the EOS in the future and should be given particular attention in further research.

*End of Season in the Southern Hemisphere*

In the southern hemisphere, the annual variability of dominating controls during EOS is not as high as in the northern hemisphere. The dominating climatic limitation for most areas is radiation, however. Since radiation is mainly a factor of day-length and is therefore not influenced by a changing climate, changes in its limitation are a result of the shift of EOS, rather than causing the shift of EOS. This makes changes in EOS much harder to analyse, since the dominant control factor can not be used to explain trends.

When looking at individual trends in climatic controls however, an increase in moisture control is observed particularly for South America. Just like the northern hemisphere, this does not translate into observable changes of EOS for the 30 years analysed. However, moisture was the only of the three controls to change significantly in South America during the last 30 years and it could therefore be expected to become an increasingly important factor for the future.

The decrease in moisture control observed for southern Africa coincides with a delay of EOS, expanding findings from section 4.2 and pointing to a more important role of moisture limitation during EOS rather than SOS, where an increase in moisture control did not lead to significant changes of the SOS date. This further supports the recent scientific change of perspective to not only concentrate on the SOS but also study changes in EOS more thoroughly (Garonna et al. 2014; Jeong et al. 2011).

*Limitations*

A strong limitation of this analysis is the focus on only 30 days prior to SOS and EOS. While it allows for a general assessment of the effects climatic controls might have on start and end of season, it does not take into account climatic changes that happen outside this 30-day window. Particularly for EOS this might proof an important next step of the analysis performed here. Since the EOS generally showed too much variability in dominating controls to find conclusive influences of climatic controls on LSP, it seems likely that drivers of changes in EOS can be found several months before actual EOS (Jeong et al. 2011).

The big challenge in the study of LSP and climate interactions remains the development of quantifiable measures of influence of climate to LSP (Richardson et al. 2013). While this thesis tried to find ways to quantify changes in climatic controls over the past 30 years, understanding the exact effects of these changes on LSP remains difficult. Since only absolute changes for individual controls were analysed, it is not possible to assess the change of relative limitations. Further research, taking into account these relative differences and changes in relative importance, is needed to better understand the processes that drive global LSP. Quantifying LSP-climate interactions requires a good understanding of the underlying processes, yet to study those on a global scale, quantifiable metrics of this interaction are needed. Hence it has to be acknowledged that LSP-climate research is an iterative process by necessity.

A second limitation is that of scale. This thesis approached the topic on a global scale and as such could only take into account large-scale phenomena. It became clear that certain regions particularly in the southern hemisphere and the tropics require a more small scale analysis to get a better understanding of the processes underlying trends in LSP. For the northern hemisphere however, the approached presented here corresponded well to regional analyses and has potential to explain large-scale effects of climate change on LSP.

The thesis looked at linear trends within a fixed 30-year window from 1982–2011, which might overlook important short-term or recent trend changes, as reported for the northern hemisphere for the period of 2000 to 2010 for example (Jeong et al. 2011). The importance of trend breaks in the analysis of LSP time-series has been discussed in scientific literature before and algorithms to find those trend breaks have been developed (de Jong et al. 2012). A next step would therefore be to build on the approach presented here and account for such trend breaks to get a more accurate picture of global change of climatic controls and LSP.