**3. Results**

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

*Comparing raw LAI data*

Correlating mean bimonthly LAI values resulted in an average person’s correlation coefficient of *r = 0.78* with a standard deviation of 0.02. There is a significant break in the first period of January 1984 (see fig X1). The average correlation coefficient from 1982 to 1983 is at 0.82 whereas the period from 1984 to 2011 is at the total average of 0.78. The correlations show a periodical minimum in the first half of September visible in all years, deviating up to 0.08 from the average.

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| **Fig. X1:** Correlation coefficients between LAIre and LAI3g for each 15-day period from 1982 – 2011 |

Yearly maxima show an average correlation coefficient of 0.86 and an average covariance of 1.82. Yearly minima show an average correlation of 0.83 and an average covariance of 0.74 and yearly means show an average correlation of 0.90 and an average covariance of 1.23. Scatterplots of yearly mean and minimum LAI values show a distinct outlier group where LAIre pixels have a higher value than the corresponding LAI3g pixels (see fig discussion.X1).

*Comparing LSP parameters*

The LSP parameter extraction for the LAI3g was successful for 14’220 pixels on average per year and excluded 6’740 non-water pixels on average every year due to a weak intra-annual variability. For the LAIre, 18’850 pixels were successfully processed and 1’840 non-water pixels were excluded. There were no significant differences in number of pixels extracted between the MI and MP extraction methods.

The annual correlation coefficients for the LSP parameters extracted with the MI method were on average around 0.38 for the GSL and EOS, and below 0.22 for SOS globally. Correlation coefficients from the MP method were around 0.55 for GSL And EOS and around 0.3 for SOS.

The lowest differences in SOS between LAIre and LAI3g can be found for the high northern latitudes with differences below 15 days for both extraction methods. This also shows in the correlation coefficients for the latitudes 45 to 90 degree north, with an average correlation coefficient of *r = 0.74* for the MP method and *r = 0.67* for the MI method. Only a few regions in the northern hemisphere show a later date for SOS for the LAIre of up to 60 days with the exception of India and east Asia where the LAIre shows an earlier SOS compared to the LAI3g. South of the tropics, the differences are more pronounced than in the northern hemisphere with differences in SOS of up to 60 days. In the tropics the differences go above 180 days. Because much of the land mass of the southern hemisphere is tropical, the correlation coefficient is around or well below 0.3 for both the MI and MP method for all 30 years.

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| **Fig. X2**: Differences in SOS (left) and EOS (right) estimations between LAIre and LAI3g (LAIre-LAI3g) for 1996 extracted with the midpoint method | |

The EOS shows a much higher global variability between LAIre and LAI3g, with parts of eastern Europe and central Asia where the LAIre shows both earlier and later dates for EOS of up to 60 days compared to the EOS from the LAI3g. The high variability leads to zero correlation for the high northern latitudes between the two datasets. The same can be seen for parts south of the Sahara in Africa and eastern Asia, albeit less pronounced, where correlation coefficients are below 0.3 for every year for both extraction methods.

The differences in GSL show growing seasons up to 60 days longer for the LAIre in the northern hemisphere, particularly in eastern Europe where the LAIre shows up to 120 days longer growing season lengths. The northernmost parts of Eurasia and America however show a shorter GSL for the LAIre of up to 60 days for some years. The southern hemisphere shows more variation with no clear large-scale over- or underestimations.

*Trend analysis 1982 – 2011*

*Decadal change for SOS*

Both datasets show a slightly earlier onset of the growing season for northern Europe and a later onset in southern America. The LAIre also shows a later onset south of the Sahara where the LAI3g lacks data. The LAI3g shows an earlier onset of SOS for China

which is much less pronounced in the LAIre.

*Decadal change for GSL*

Both datasets show a shortening of GSL in south America as well as in the east of southern Africa. They also both show a lengthening of GSL in northern Europe and China and in the west of southern Africa. Different results are seen south of the Sahara with the LAI3g indicating a slight GSL lengthening and the LAIre showing a shortening (see fig, X).

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| **Fig. X3**: Trends in in Growing Season Length from 1982 – 2011 for LAI3g (left) and LAI3g (right) in days/decade. Differences are visible particularly in the Sahel. | |

*Decadal change for EOS*

Both datasets show a trend of a later EOS for southern Africa as well as in southern America. The LAI3g shows a later EOS for northern Europe, which is not visible in the LAIre dataset. The LAIre however shows a trend towards an earlier EOS for Central Asia, which is not visible in the LAI3g dataset due to lack of data.

***3.2 Climatic Controls***

*3.2.1 Yearly Dominating Control*

Temperature is the dominating yearly control factor for the higher latitudes of the northern hemisphere. Radiation is shown to be the main control factor for the eastern USA, Europe and East Asia. Moisture is the dominating control for the Middle East and most of Africa as well as most of Australia. The tropics are controlled by radiation, as is most of South America.

Changes in the dominating yearly control factor over 30 years can mainly be found along the borders of areas of different dominating controls (fig X). Exceptions to that are South America and Scandinavia. Large regions in Brazil show a clear shift in domination from radiation to moisture between 1982 and 2011. Scandinavia shows large-scale inter-annual variations of dominating controls, changing between radiation- and temperature-dominated years. A domination change between all 3 controls can only be seen in Central Asia, where areas of all three domination controls meet.

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| **Fig. X4**: Yearly dominating controls in 1982 (left) and 2010 (right) showing large-scale change in moisture control in Brazil | |

*3.2.2 Quarterly Trends for Climatic Controls*

*Temperature*

The analysis of the bimonthly change of temperature control per decade showed almost no increase in temperature control globally. The only exceptions are eastern Australia and South-western Canada during the second quarter of the year, where an increase in control of around 3% can be observed.

A strong decrease of temperature control can be observed in the first quarter of the year for the Middle East and central Asia with decadal change of over 20% in some parts. The second quarter shows a decrease of temperature control in the northern latitudes, particularly Greenland and north-eastern Siberia with changes of around 15% to 20% per decade. For the third quarter, the same can be observed for the high latitudes of northern America. The fourth quarter shows a decrease in temperature control factor of around 10% in eastern Europe.

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| **Fig. X5:** Changes in temperature limitation by quarter | |

*Moisture*

The moisture control shows a decrease of about 10% per decade for southern Africa in the first quarter of the year. Starting around March until May, the Middle East and south of the Sahara show an increase in moisture control of around 10% per decade. The second quarter also shows an increase in moisture control for the Gobi desert of over 10%. The third and fourth quarter shows an increase in control for South America, mainly around Brazil of over 10% per decade. Also in the fourth quarter an increase in control of over 10% for the south-eastern edge of the Sahara can be seen.

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| **Fig. X6:** Changes in moisture limitation by quarter | |

***3.3 Influence of Climatic Controls (CC) on Phenology***

The analysis of climatic controls in the 30 days prior to SOS and EOS showed similar results for LSP parameters extracted from either dataset. The main differences can be found in the exact spatial extent and intensity of observed shifts, but do not affect the general trends found in the data. Therefore, the results presented here apply to both datasets, except where explicitly stated otherwise.

*Dominating Climatic Control during SOS and EOS*

*Dominating controls at Start of Season*

At SOS the dominating control for the northern hemisphere is mainly temperature for higher latitudes and radiation for lower latitudes. At the SOS moisture is the dominating limiting factor in the subtropics and radiation in the tropics. In the southern hemisphere the main limiting factor is moisture in the subtropics and radiation in the south of Africa, south of Australia and some parts of southern America. Only small parts of southwest America and south-eastern Australia are affected by temperature controls.

The time-series of dominating controls during the SOS shows that the areas unaffected by changes in dominating controls, apart from desert and high mountainous areas, are in Siberia and parts of Canada, where the dominating control is temperature over all 30 years. A lot of change can be observed in Europe and central Asia where the dominant control varies between temperature and moisture control. The southern hemisphere mainly shows small variations in the extent of moisture-controlled and radiation-controlled areas.

*Dominating Controls at End of Season*

At EOS the northern hemisphere is dominated by radiation for most parts of central and eastern Europe, east and south Asia and the east of north America. Central Asia, the Middle East and the north of Africa are dominated by the moisture control during EOS, as is the western part of the USA. The temperature control only dominates very high northern latitudes. The southern hemisphere is also mostly radiation controlled at EOS with the exception of Australia and southern Africa, which are mainly moisture controlled.

The time-series over the last 30 years showed annual changes between all 3 controls for most of the higher northern latitudes. The rest of the world only shows small variations around the border regions of dominating controls, mainly between moisture and radiation controlled areas.

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| **Fig. X7**: Dominating controls at EOS for the years 1991 (left) and 1992 (right) showing big variability particularly for Europe and Northern America | |

*Shift in Climatic Controls during SOS and EOS*

*Moisture*

At SOS a strong increase in influence of the moisture control can be seen in southern America of around 5% to 10% per decade, and in some areas even up to 14% per decade. A strong increase in control can also be observed south of the Sahara with an increase of about 10% per decade. A decrease in control can be observed in western Africa, along the eastern Indian coast as well as north east Asia, particularly in the LAIre dataset. Almost no change in the influence of moisture control during the growing season for the northern hemisphere can be observed.

At EOS a slight increase in moisture control for the northern hemisphere (around 1% – 5% per decade) and some areas in central and eastern Asia (over 13% per decade). A slight increase in moisture control can also be seen in southern America with a rate of about 3-9% per decade. In southern Africa and eastern Australia a decrease in moisture control of around 10% can be seen.

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| **Fig. X8:** Shifts in moisture limitation at SOS (left) and EOS (right) from 1982 – 2011 based on SOS/EOS extracted from LAIre | |

*Temperature*

The temperature control shows a decline in influence at SOS of up to 15%/decade in Scandinavia, parts of central and eastern Asia as well as Brazil and southern Africa. An increase of temperature control was only observed around the Gobi desert (-13% per decade) and in north-eastern America (-5%/decade). At EOS a decline in control can mainly be seen in the northern hemisphere with no significant major changes in the southern hemisphere.

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| **Fig. X9**: Shifts in temperature limitation at SOS (left) and EOS (right) from 1982 – 2011 based on SOS/EOS extracted from LAIre | |

*Radiation*

In the northern hemisphere, radiation becomes a stronger control at SOS with a rate of up to 10% per decade, except for parts of northern America where the effect is not as strong with only about 1-5% increase in control. Southern Africa shows a strong decrease in radiation control at SOS of about 10% per decade. A decrease at SOS can also be seen in southern America where the increase is up to 8% per decade.

Change rates during the EOS show less agreement between the two datasets. The two regions where they agree are eastern Asia and southern Africa, where an increase of radiation control at around 5% per decade can be seen at EOS. The LAI3g also shows an increase in radiation control of about 7% for many parts of north America, Europe as well as the Sahel, where the LAIre does not show any major change in control factor. The LAIre however shows a decrease of the radiation control of around 7% per decade in central Asia.

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| **Fig. X10**: Shifts in radiation limitation at SOS (left) and EOS (right) from 1982 – 2011 based on SOS/EOS extracted from LAIre | |

*Correlation of changes in LSP to changes in Climatic Controls*

Correlation coefficients for the comparison of changes in LSP parameters and changes in climatic controls over the last 30 years can be seen in table X. The moisture control shows a strong negative correlation for SOS at -0.61 for LAIre and a slight negative correlation of -0.23 for the LAI3g. LAIre also shows a small positive correlation for EOS and Moisture of 0.22. The temperature control shows no correlation for either dataset. The light control shows a small correlation for SOS of r = 0.35 for LAIre and 0.28 for LAI3g.