**Title**

**Introduction**

The effects of anthropogenic climate change on vegetation dynamics have received increasing attention of the scientific community in the past decades (Schwartz 1999; Richardson et al. 2013), as global and regional changes in land surface phenology (LSP) have been documented (de Jong et al. 2012; Garonna et al. 2014; Jeong et al. 2011; Anwar et al. 2015; Badeck et al. 2004; Julien & Sobrino 2009). To understand the processes underlying these changes in LSP and to be able to make predictions for the future, the feedback loops of phenology and the climate system have to be investigated (Richardson et al. 2012; Richardson et al. 2013). Developing climate based LSP models and comparing them to the effects observed in satellite and field data is seen as an important step to investigate these complex interactions (Schwartz 1999; Jolly et al. 2005).

A promising concept to model phenology is based on climatic factors limiting plant growth, also called climatic controls (Jolly et al. 2005). Jolly et al. developed a Growing Season Index (GSI) based on temperature, vapour pressure deficit (VPD) as a measure of moisture availability and photoperiod to quantify energy availability. Others (Stöckli et al. 2011) have used and extended the GSI to perform a global reanalysis of vegetation phenology, creating global modelled time-series of vegetation indicators such as the Leaf Area Index (LAI). The LAI is defined as half of the green leaf area relative to the ground area, usually with values ranging between 0 and about 8 m2/m2 (Chen & Black 1992; Fernandes et al. 2014).

Most studies on long-term LSP trends based on remotely sensed data (de Jong et al. 2011; Garonna et al. 2014; Jeong et al. 2011) however rely on the Normalized Difference Vegetation Index (NDVI) (Tucker 1979; Rouse et al. 1973). Since the NDVI is merely a proxy of vegetation activity based on the reflectance of visible and infrared radiation, its application for understanding underlying processes is limited (Myneni et al. 1995; Carlson & Ripley 1997; Jiang et al. 2006; Jin & Eklundh 2014).

An increasingly popular indicator which can be derived from remotely sensed data is the LAI, which contrary to the NDVI allows a direct link to ground conditions (Zhu et al. 2013; Jiang et al. 2010). Satellite based LAI products have been available from the Moderate Resolution Imaging Spectroradiometer (MODIS) and SPOT/VEGETATION (Baret et al. 2007) platforms for the past decade (Fang et al. 2012) and have been used for short-term LSP studies (Verger et al. 2015; Anderson et al. 2015). Longer LAI time-series have also recently been made possible by linking 30 years of Advanced Very High Resolution Radiometer (AVHRR) NDVI data to the available MODIS LAI data (Zhu et al. 2013).

With the emergence of long-term LAI time-series, it has become possible to compare modelled LAI datasets such as the reanalysis done by Stöckli et al. (2011). This not only gives us a chance to verify the models, it also allows us to study the impact of the climatic controls underlying the model might or might not have had in the past 30 years.

Of particular interest to LSP researchers are parameters indicating the start of spring events called Start-Of-Season (SOS) and senescence, usually called End-of-Season (EOS) (Garonna et al. 2014). Quantifying and understanding the changes of climatic controls over the past decades during these events is of particular interest for researchers (Jeong et al. 2011; Richardson et al. 2013).

**Aims & Research Questions**

The focus of this master thesis lies on the analysis of the impact of global changes in climatic controls on global land surface phenology. However, a validation of the underlying data has to be performed first, followed by an analysis of the climatic control changes that happened over the last 30 years, before their impacts on changes in LSP can be investigated. Therefore, each chapter of the thesis will be split into 3 parts to deal with each of the following 3 topics.

First the modelled LAIre has to be compared to the measured LAI3g to validate the climatic controls model. Of major interest for validation are LSP parameters SOS and EOS extracted from the two dataset. The validation will not only justify the use of climatic controls to explain changes in LSP, but by investigating differences in the modelled and measured data, it will also help understand where changes in climatic controls might not be the main drivers of LSP. Therefore, the main question to be answered for that is: How well do LSP parameters (such as SOS and EOS) extracted from the two datasets correlate and where do they differ?

Then, the three climatic controls, temperature, VPD and radiation, on which the modelled LAIre is based are analysed to gain an understanding of the changes in global climatic limitations for plant growth. Inter-annual changes in dominating controls are investigated as well as changes in the strength of individual controls over the last 3 decades. This will be used to answer the question: Are there changes in dominating climatic controls or in individual controls over the last 30 years?

Lastly, climatic controls at the time of SOS and EOS and their changes over the last 30 years will be analysed to gain an understanding of the processes influencing these important phenological stages. The 30 days of climatic controls right before SOS and EOS will be looked at. Dominating controls during that time and changes in individual controls will be examined to answer the question: Are there inter-annual changes in global dominating or individual climatic controls at SOS and EOS?