Drought impact on Swedish terrestrial ecosystems - detecting and mapping vegetation change

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Application approved by Head of department for Physical Geography and Ecosystem Science, professor Petter Pilesjö, confirming that we will host the PhD student and finances the remaining part (25%) of the studentship.

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Introduction

The recent (2018) drought reduced the Swedish cereal harvest (Figure 1), reduced available grazing resources and lowered the harvest of animal feed[1], crucial for maintaining national food production and to sustain animal stocks over the winter. The 2018 cereal harvest was the worst since the late 1950's[2]. Effects on forest and forestry are still partly unknown but reduced carbon uptake have been observed [1] and drought induced bark beetle outbreaks in southern Sweden have been reported[3]. The rate of recovery and implications for forest production and economy remain to be analysed.

Extreme weather events impact ecosystem services both locally and nationally and on various time scales. The frequency and magnitude of extreme weather events is expected to further increase during the 21st century [2]. Single extreme events cannot generally be directly attributed to anthropogenic influence, and there are significant uncertainties regarding trends in drought occurrence [3]. Impacts resulting from projected changes in extreme climate events related to drought include decreased crop yields, decreased water resource quantity and quality, increased fire risk and risk for insect infestations [4, 5]. While both forestry and agricultural may be affected by a range of extreme weather events, this project focuses on drought related effects. Economic losses from weather- and climate-related disasters have increased, but with large spatial and interannual variability [6].

Drought can be defined in various ways, here we use soil moisture drought, induced by a shortage of precipitation during the growing season but also influenced by evaporation, soil depth and management as well as carry over effect from previous seasons [6].

Preliminary work, based on Earth observation (EO) estimates of deviations in leaf water content illustrates strong drought effects in North-west Europe in 2018 (Figure 2). These preliminary observations will in this project be further investigated at several temporal and spatial resolutions using a range of EO sensors and methods in combination with various in-situ observations.

The novel European Sentinel-2 satellites provide a so far **unprecedented opportunity** for ecosystem monitoring at 10 meter spatial resolution and a revisit time of 3-5 days in Sweden, in combination with excellent spectral properties designed for vegetation monitoring [7]. This capability will be utilized and explored in this project.

Overall aim

The overall aim of the project is to develop, test and apply methodology for detection and quantification of spatially explicit drought effects on Nordic agricultural and forest ecosystems and their productivity. Furthermore, it aims to develop readiness for the next drought by developing policy and management capability based on remote sensing integrated with meteorological and other environmental data.

Specific aims

1. Develop and test change-detection methodologies for terrestrial vegetation based on time series information from new EO satellites at high spatial and temporal resolution.
2. Quantify and understand spatially explicit drought related changes in agricultural ecosystems.
    a. Identify drivers and map areas with high risk of disturbances.
    b. Quantify effects on production and the carbon cycle.
3. Quantify and understand spatially explicit drought related changes in forest ecosystems.

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[1] http://www.jordbruksverket.se/omjordbruksverket/krisberedskap/torkan2018/lagesbildochallmannaradomtorkan.4.75b78d1115c593393d4dedde.html

[2] https://lantmannen.com/press-och-nyheter/nyheter/svenska-skorden--lantmannen-presenterar-en-uppdaterad-skordeprognos/

[3] https://www.sodra.com/sv/skog/nyheter-och-aktiviteter/nyheter/2018/alla-vo/sommarens-torka-gynnsam-for-granbarkborren/)

   a. Identify drivers and map areas with high risk of disturbances (insects).
   b. Quantify effects on forest growth and the carbon cycle.
   c. Investigate lag effects on the following vegetation seasons.
4. Develop management recommendations to mitigate direct and adverse secondary effects (insect outbreaks) of drought on crucial Swedish ecosystem services within forestry and agriculture.

BECC Significance

This project concerns two BECC themes; *Ecosystem Services* and *Carbon & Climate Change.* Drought and other extreme weather events may strongly impact the carbon cycle as well as ecosystem services provided by agriculture and forestry [8]. This affects the resilience of our society due to deficits in agricultural production (Figure 1) and increased susceptibility of forests to insect infestations and fire [8]. This will influence public and private values of ecosystem services whereas the understanding, mapping and quantification of these impacts are crucial for development of sound management and relevant policies. Data from the 2018 drought (e.g. Figures 1, 2) will be collected and used as a basis for studying and investigating drought effects while recognizing that the frequency of similar events is expected to increase [3]. Integration of scientists from two faculties provides multidiscipline approach suitable for successful stakeholder interaction.

Planned Research

Each aim above corresponds to a work-package (WP) described below. WP1 cover required method and algorithm development whereas WP2-3 cover applied research related to agriculture and forest. WP4 integrate results into drought strategies. The PhD candidate will be a part of CLIMBECO and INES research education and will work in close cooperation with supervisors and a designated post-doc in order to coop with this somewhat ambitious project.

Project dissemination through BECC channels, publications and stakeholder workshops.

WP1: Development of change detection methods for time series of EO data

Normal vegetation development follows annual trajectories in leaf area index (LAI) and productivity as a function of meteorological drivers (temperature, radiation, and water availability) in combination with management activities such as seeding, thinning, harvest, fertilization and irrigation. Deviations from a typical trajectory may be detected using EO data, using platforms such as MODIS, VIIRS, PROBA-V and the recent 10-meter resolution Sentinel-2.

On many occasions for monitoring change in vegetation cover, coarse models (usually linear) are applied with little consideration as to their suitability for describing change across time. This can lead to poor metrics for the detected changes because the climate-vegetation system is highly dynamic and it should be described by methods that are more flexible.

WP1 focuses on generation of improved change/trend detection methods for EO data, based on sequences of fits to linear and non-linear functions, and time-series segmentation methods. Fits to polynomial functions are used in a method (PolyTrend) developed for analysis of non-linear vegetation change using time-series of EO [9]. It presents an entirely automated method, as a development of Ordinary Least Squares (OLS), for detecting non-linear trend behaviour (e.g. drought impact on vegetation). To analyse temporal variations more accurately and to detect abrupt breakpoints (e.g. harvest, drought, or fire impact on vegetation), a time-series segmentation method, named DBEST (Detecting Breakpoints and Estimating Segments in Trend) is also used [10]. It is a fast, accurate and flexible tool for both detecting breakpoints and gradual changes and estimating their timing and magnitude.

To further improve the benefits of the developed time-series analysis methods (PolyTrend, DBEST) to a broader community and advance vegetation change/hotspot mapping with big EO data, the methods are implemented in the Google Earth Engine (GEE). GEE is attractive because of its very broad and growing user base, full access to the Landsat archive, time series data preparation and management, and ease of parallel processing [11]. The GEE team has worked in close collaboration with Google Cloud to bring the Landsat and Sentinel-2 collections to Google Cloud Storage as part of the public data program.

WP2: Agriculture

Here we apply in-house developed methods for quantification of vegetation development [12] and phenology [13] using time series of high resolution EO data in combination with the methodological output from WP1. This will provide state of the art handling of time series of EO data with reliable estimates of leaf area index (LAI), water status [14, 15] and related changes in plant productivity. The extensive European knowledge base related to agricultural monitoring [16] will be utilized as support. Both gradual vegetation change (due to drought) and abrupt change (harvest) in agricultural ecosystems will be studied. A range of environmental settings (soil types, drought severity) crops and crop management practises will be investigated to cover a range of potential cases of drought impact.

Detected deviations and changes will be validated versus a range of data sets to answer the question '*how well can drought induced changes in agricultural ecosystems be detected, mapped and quantified?' Detected* indicates where in a time series the change happened, *mapped* is spatial accuracy and delineation of the deviation whereas *quantification* refers to biomass/harvest deviation from normal.

Validation data include in-situ measurements (spectral properties, meteorological, soil moisture availability, CO_2-fluxes etc.) from research sites (ICOS[4]; Lanna, SITES[5]; Lönnstorp, Rödbäcksdalen) and available harvest statistics and field trials from Hushållningssällskapet, Jordbruksverket (Mattias Gotting) and Skottorps Säteri[6].

Based on relationships found we will detect, map and quantify drought induced changes in agricultural ecosystems for selected Nordic areas dominated by agricultural ecosystems. This will be evaluated versus regional statistics and inventories (e.g. Figure 1 and similar data),

WP3: Forestry

Forests at higher latitudes are predicted to be strongly influenced by climate change and associated disturbances [5, 17]. In WP3 we will study both the direct effect of the drought in 2018 on the carbon cycle and secondary effects due to drought induced bark beetle outbreaks. Direct effects on carbon uptake will be studied with the aid of CO_2-flux data from ICOS. For secondary effects we have access to insect outbreak data from forest managers and agencies. To limit the impact of bark beetle outbreaks methods to monitor outbreaks in near real-time over large areas are required. We have previously developed methods for mapping of forest disturbances in near real-time, with the aid of coarse spatial resolution data from the MODIS sensor [18] but in fragmented forests the coarse spatial resolution is a major limitation [19]. Methods for forest monitoring based on higher spatial resolution data from Landsat have been developed [20-22], but the low temporal resolution of Landsat is a limitation for early-warning systems. Therefore, there is a strong urgency to develop time-series methodology for Sentinel-2 data. In addition to higher spatial and temporal resolution compared to Landsat, Sentinel-2 also has a larger number of spectral bands which has proven to be an advantage in detection of bark beetle outbreaks [4].

For efficient mitigation it is important to detect bark beetle outbreaks already at early stages, i.e. during the green attack [23] when trees look healthy to a human eye but the new generation of bark beetles is developing within the infested trees. These green attack trees must be removed from the forest to prevent bark beetles to spread to surrounding trees. For early detection we will utilize longer wave length bands, that are sensitive to leaf water content, such as shortwave infrared (SWIR) wavelength bands that have proved successful for detection of insect defoliation [24, 25]. In addition, it is important to monitor forest health to identify high risk areas since stressed trees, e.g. due to drought, are more sensitive to bark beetle attacks [4, 5].

WP4: Management/Policy

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[4] Integrated Carbon Observation System, http://www.icos-sweden.se/

[5] Swedish Infrastructure for Ecosystem Science, http://www.fieldsites.se/sv-SE

[6] Lars-Inge Gunnarsson, >3000 ha cultivated, http://www.skottorpssateri.se/

The results from WP2-3 will be integrated into a framework for estimating drought-vulnerability. Combinations of environmental/abiotic drivers (meteorology and soil), management and crop/tree types and spectral changes will be the basis for a drought risk assessment allowing identification of areas at risk given a certain drought-scenario. The year 2018 provides a **unique opportunity** to further study the impact of drought on ecosystem services provided by agriculture and forestry. This WP will be developed in cooperation with stakeholders within forestry (Skogsstyrelsen/Skogssällskapet, T-kartor) and agriculture (Jordbruksverket, Hushållningssällskapet, Skottorps Säteri).

Budget and time plan

The salary for a PhD candidate to be financed by 75% by BECC (Table 1). Remaining salary (25%) and running costs will be covered by the applicants' departments. Table 2 describe the time plan.

Table 1 Budget, all costs in KSek.

Item	Description	Cost
PhD candidate salary	Salary 4 years x 0.75	1672
Overhead cost	32.35% (Premises and Indirect costs)	557
Sum		**2229**

Table 2. Time plan for quarter 1-4 per year.

Year	Q1	Q2	Q3	Q4
1	Start-up	WP1	WP1	WP1
2	WP2-3	WP2-3	WP2-3	WP2-3
3	WP2-3	WP2-3	WP2-3	WP2-3
4	WP4	WP4	WP4	Finalizing

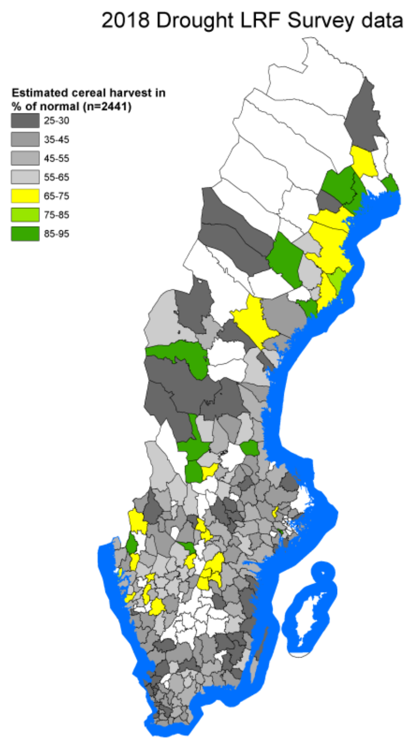

Figure 1. Estimated 2018 cereal harvest (in percent of normal) per county (kommun) in Sweden based on LRFs's harvest survey (white = no data).

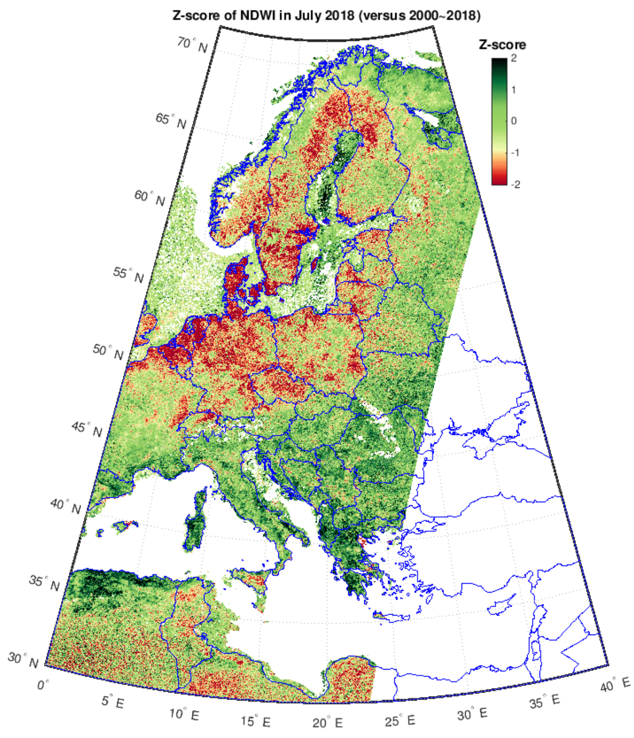

Figure 2. Normalized drought impact for July 2018 as compared to the 2000-2018 period. NDWI is the normalized difference water index describing vegetation water status It is based on data from the MODIS sensor with 500 m spatial resolution.

Involved scientists

Professor **Jonas Ardö** (BECC PI) with extensive experience in combining Earth observation and in-situ measurements for quantitative studies related to ecosystem services and the carbon cycle. PhD **Sadegh Jamali**, LTH, with extensive experience in development and application of change detection methods for vegetation, based on time series of EO data. PhD **Per-Ola Olsson** with extensive experience in remote sensing of insect disturbances based on time series of EO data. Professor **Lars Eklundh** (BECC PI), co-ordinator of the SITES Spectral network with operational collection of data from drones, satellite and ground sensors across Nordic agricultural and forest ecosystems and leader of a BECC project on agricultural intensity and biodiversity. Scientists from ICOS and SITES will be involved as needed. Suitable candidates for the PhD-candidate positions exist. Ardö will be main supervisor and Sadegh, Olsson and Eklundh will be co-supervisors for the PhD candidate.

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