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Monitoring of plant productivity in relation to climate on Svalbard

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1 FOREWORD

The work is funded by the Svalbard Environmental Protection Fund with 150kNOK and the ESA PRODEX project ‘Sentinel-2 for high north vegetation phenology’. The work with processing a cloud-free time-series of Landsat data has also been a master thesis to Laura Stendardi. We are grateful to Elisabeth Cooper at the Arctic University of Norway, who has contributed with the method development of field measurements. Processing of the MODIS dataset for monitoring the onset of the growing season was, in part, funded by the Environmental Monitoring of Svalbard and Jan Mayen (MOSJ). We are grateful to senior advisor John Richard Hansen, who is our contact person at the Norwegian Polar Institute in MOSJ for his support.

Contents

2 BACKGROUND

The Arctic is changing rapidly due to global warming. Even in extremely low productivity systems such as Svalbard, the available plant biomass supports large populations of reindeers and other herbivories. Given the predicted future warming at such high latitudes, the development of a cost-efficient and proper tools for monitoring variation in plant productivity is crucial for our understanding of ecosystem responses to climate change, for management of reindeer populations, and for estimating the carbon uptake. However, carrying out long-term field-based studies of plant productivity in plant-based food webs is labor intensive, and their spatial coverage is very restricted. Satellite image-aided analysis of plant productivity provides a method for determining complete coverage that can be used to interpolate traditional ground-based estimations of biomass. With the new generation of polar orbit satellite sensors with both high spatial (10-30m pixels) and temporal (daily to weekly) resolution, like Landsat 8 (launched in 2013) and Sentinel-2 (launched in 2015), it should now be possible to measure annual plant productivity with time-series of these sensors. However, field validation data designed to be up-scaled by these sensors is needed.

In this project we first do a study with MODIS satellite data with 250m pixel resolution (Karlsen et al. 2014) and compare it with climatic data. This study gives relative values of plant productivity for the last 15 years, as well as identifies the climatic drivers. The next step in this project is then to establish permanent plots for annual non-destructive measurements of plant productivity, which can be upscale for larger areas, based on Landsat 8 and Sentinel-2 satellite data, and then give more exact values of plant productivity.

3 CENTRAL SVALBARD – PLANT PRODUCTIVITY IN RELATION TO CLIMATE

The satellite-based normalized difference vegetation index (NDVI) value is based on the difference in reflectance in the red and the near-infrared parts and has a strong relationship with plant biomass. Previous, a cloud-free time-series of NDVI based on MODIS satellite data for Svalbard for the 2000 to 2014 period has been processed, which have been used to map the onset of the growing season (Karlsen et al. 2014). The MODIS-NDVI dataset has 250m pixel resolution and are interpolated to daily time resolution. In this study we calculated time-integrated NDVI (TI NDVI) values from the time of onset of growth until the time of maximum growth (average 2000-2014). These TI NDVI values will then show areas with average high or low plant production (Figure 1). The map shows that large areas of the central valleys (Colesdalen, Adventdalen, Sassendalen and Reindalen) have relative high plant production. We also compared the TI NDVI values with temperature data from the Svalbard Airport meteorological station located close to Longyearbyen, and also found a highly significantly relationship (Figure 2, $p < 0.001$). By utilizing these relationships, we have characterized the annual plant productivity each year for the 2000 to 2014 period in relation to temperature (Figure 3).

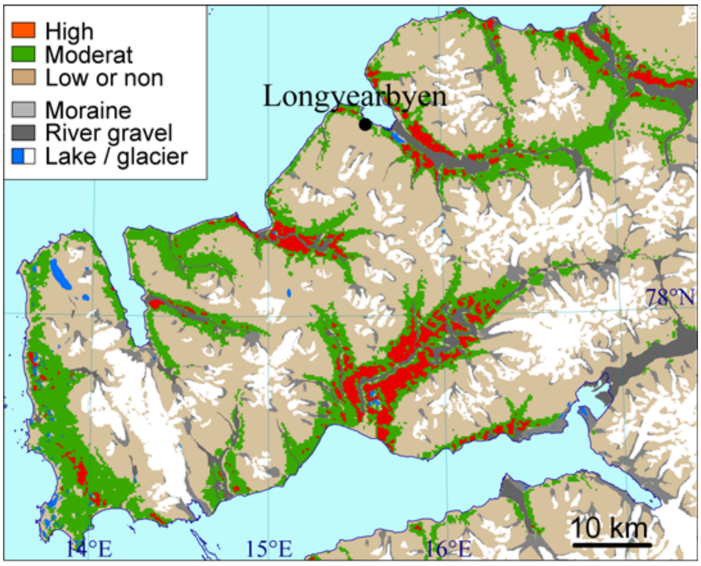

Figure 1. Average plant production on Nordenskiöld Land. Mean (2000-2014) NDVI values integrated form time of onset of growth until time of maximum NDVI. High values (red) shows areas with average high annual production.

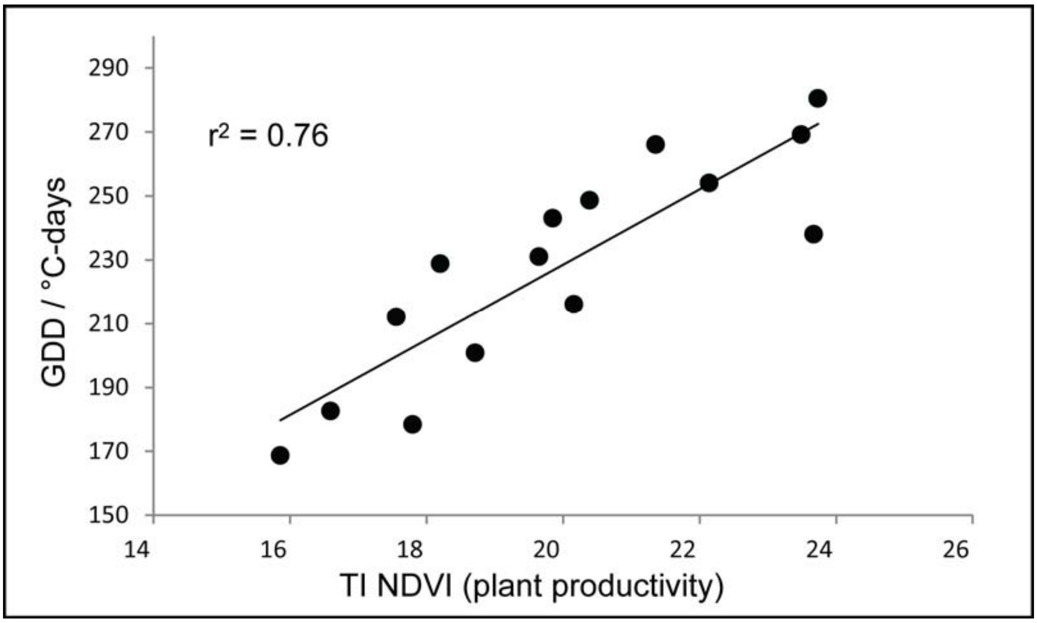

Figure 2. Relationship between time-integrated NDVI (TI NDVI) and growing degree days (GDD). Integrated values form time of onset of growth until time of maximum growth.

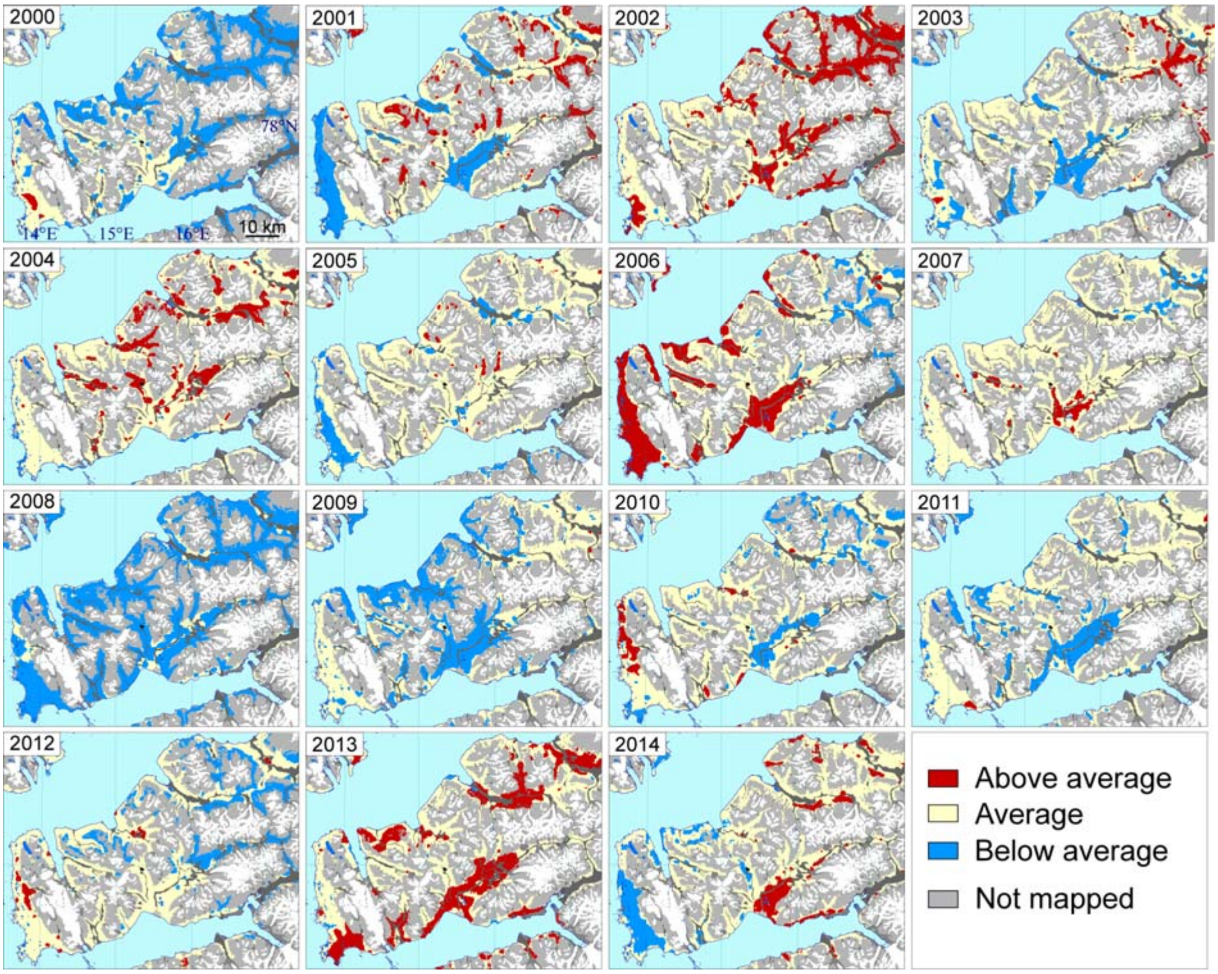

Figure 3. Variation in plant productivity relative to the 2000-2014 average. Red indicates higher than average plant productivity and blue lower than average.

The results show that the summer of 2008 was generally the most extreme year in terms of low plant productivity (blue on Figure 3), followed by the years 2000 and 2009. On the other hand, the years 2002, 2006 and 2013 were years with higher productivity than the 2000-2014 average. By utilizing the significant relationship between TI NDVI and temperature data we can also relate the annual maps (Figure 3) to daily temperature sum above zero degree from the time of onset of the growing season until the peak of season (Figure 2). The red colour then indicates a warm summer with daily temperature sum of more than 50°C-days above the 2000-2014 average, and blue a cold summer.

This MODIS-based study only shows relative values, indicating years with relatively high or low productivity. To give more exact numbers of plant productivity (gram per square meter dry weight per year) then higher pixel resolution and field data designed for up-scaling with satellite data is needed. However, the study shows that it is important to first measure the onset of the growing season and the peak of growth, because the time-integrated NDVI value from onset to peak then give best fit with plant productivity. The study also shows that the annual plant productivity on landscape level is highly controlled by temperature. This relationship can be used to predict further plant productivity based on climate change scenarios.

4 ADVENTDALEN - PLANT PRODUCTIVITY ON FIELD SCALE

To have more exact values of annual plant productivity we need to work on species and plant community scale. To do this we have in this study established permanent plots for field measurements in Adventdalen valley, designed to be up-scaled by time-series of high-resolution satellite data.

4.1 SELECTION OF SPECIES AND STUDY SITES

We selected the two species tundra-grass/tundragrass (*Dupontia fisheri*) and wood-rush/vardefrytle (*Luzula confusa*) for plant productivity study. *Dupontia fisheri* is often dominated or sub-dominated on wet to mesic sites. *Luzula confusa* is widespread on Svalbard and often dominate or sub-dominate on mesic to dry sites. Hence, these two species together cover a large moisture gradient. To select study sites for both destructive and non-destructive measurements, which can be used as validation sites for satellite data, we used Formosat-2 satellite data with 8m pixel resolution covering the Adventdalen area. From a Formosat-2 images from 19 July 2011 we developed a NDVI map (Figure 4) and a vegetation map, and then we located homogeneous areas in vegetation and NDVI. Then we located areas where *Dupontia fisheri* or *Luzula confusa* were dominated or sub-dominated. In field, polygons representing the sites were drawn (Figure 4), using ArcPad software on handheld Windows device.

4.2 RELATIONSHIP BETWEEN DRY WEIGHT AND HEIGHT ON SPECIES LEVEL

4.2.1 Field data - method

To establish site where plant productivity can be measured each year by only measuring the height and cover of the plants, we first have to establish a relationship between height/cover and weight. Hence, we first have to carry out destructive measurements (cutting grass) to establish this relationship. In the selected homogeneous site, we had 10 samplings along one transect of about 30m (one Landsat pixels). For each 3 m we located the closed homogeneous stand of the species. Then in the homogeneous stands we marked 18 x 18 cm and estimated the cover of either the *Dupontia* or *Luzula* species (mean cover value from two of the observers). Most often the cover was 100% or close to 100% of the species. Then we measured the height of the leaf from the moss layer to the top of the leaf/stem. After measuring the height of the leaf/stem we cut all species within the 18 cm x 18 cm at the moss layer. Then (in office) we sorted out other species/mosses/waste - from *Dupontia*, we removed all dead and other species/waste in the sampling, - from *Luzula* we separated dead/brown leaves from living/green leaves right after cutting for 2-4 of the sampled of each sites. We were only interested in the annual growth of the species - the living green biomass at species level. The samples were then dried in 24 hours on 60°C. Finally, the dry weights were measured and the relationship between dry green biomass and height were estimated for both the selected species.

4.2.2 Field data - results

Dupontia fisheri: A total of 20 samples from two different sites of *Dupontia fisheri* marshes were collected, where each sample was 18 x 18 cm. After drying, the total green biomass (leaves + stem) was on average 76% of the total (green + dead) biomass, ranging from 54 to 88%. The correlation between height of leaves and dry weight for green leaf biomass was high and significant in a linear relationship (r^2=0.85, n = 20). We also tried logarithmic (r^2 = 0.87) and polynomial (r^2=0.88) relationship – which were slightly better than linear. Hence, for *Dupontia fisheri* we have established a good relationship between height of leaves and dry weight, which mean than we annually can measure the height of leaves and then calculate the weight of the green biomass. The results show that a mean leaf height of 15 cm represents 160-gram dry weight of green biomass of *Dupontia* in a 1x1m with 100% coverage. A relationship was also found between stem height and dry weights, however, on average the stems accounts for only 5.4% of the total living green weight.

Luzula confusa: A total of 30 samples from two different sites of *Luzula*-heaths were measured and collected. *Luzula confusa* is characterized by lots of dead/brown leaves from the year(s) before, and we wanted the weight of the annual green leaves. In 13 of the total 30 destructive samples we sorted the green leaves and stems from the dead/brown leaves and stems. On average the green leaves accounted for 53 % of the total weight. We also looked at the relationship between fresh and dry weight in the 30 samples and the results indicate that fresh weight is about twice as high as dry weight – this due to the high contents of dead leaves in *Luzula*. Before sorting out dead leaves/stems the correlation between height of leaves and dry weight was significant in a linear relationship (r^2=0.56, n = 30), however, when sorting out only green leaves/stems the correlation decrease.

4.2.3 Establishment of permanent plots for annual measurements

In one *Dupontia* site and in both of the *Luzula* sites we established permanent plots. In each site we established 8 permanent plots. Each plot is 18 cm x 18 cm, and was marked with bamboo sticks in each corner, then these plots was divided in 6 cm x 6 cm squares. We first estimated the cover of the species (mean from two observers), and had systematically photo from above and from side, standing on the northern side of the plot to avoid shadow. Then we measured in each 6 x 6 cm square, from NE, NE, SE, SW, we measured the five highest leaves in each 6 cm square and we measured every stem. At each site also one temperature logger (LogTag) was dig down and automatic time-laps camera (also called trail camera or PhenoCam) established. These cameras having photo each hour every day from 9 am to 4 pm and are used to determine the time of onset and peak of the growing season.

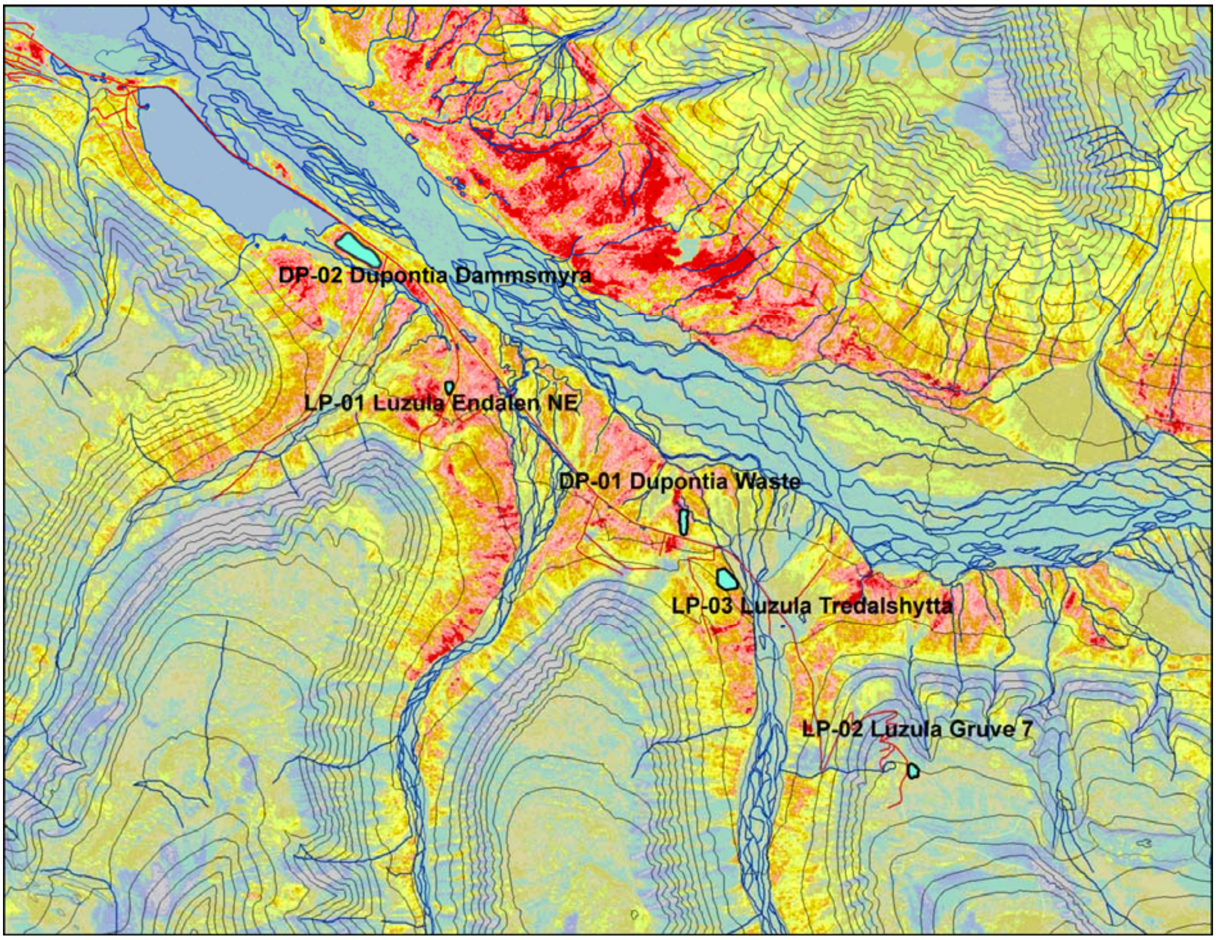

Figure 4. Adventdalen valley. Showing NDVI values from Formosat-2 satellite image from 19 July 2011 and locations of the sites with field measurements.

Figure 5. Dupontia site DP01, showing placement of time-laps camera and one of the eight permanent plots.

DP-01 Dupontia site

On the northern side of the road, in the ‘flow’ from the Longyearbyen waste deposit permanent plots were established (Figures 4 and 5). The site is variable and with different species dominating (*Eriophorum scheuchzeri* ssp. *arcticum*, *Calamagrostis neglecta* ssp. *groenlandica*, *Carex subspathacea*). However, two well-defined areas were located based on

NDVI data from Formosat-2 and field work. Northern parts have less water, while in south the creek is wider - the water will influence the NDVI value, hence, two different polygons were extracted in field, and only the largest is shown on the map. Eight permanent plots were established, and at the site a time-laps camera and a temperature logger was established. It is a very luxuriant site, probably among the sites with the highest productivity on the entire Svalbard, and for the 2015 season the results show that the plant production was on average 168 gram per square meter at this site (dry green biomass, assuming 100% cover of *Dupontia*).

DP-02 Dupontia site

A site in the Dammsmyra wetlands (Figure 4). Only destructive samplings in 2015, however, sites are located, and establishment of permanent plots is planned for the 2016 season.

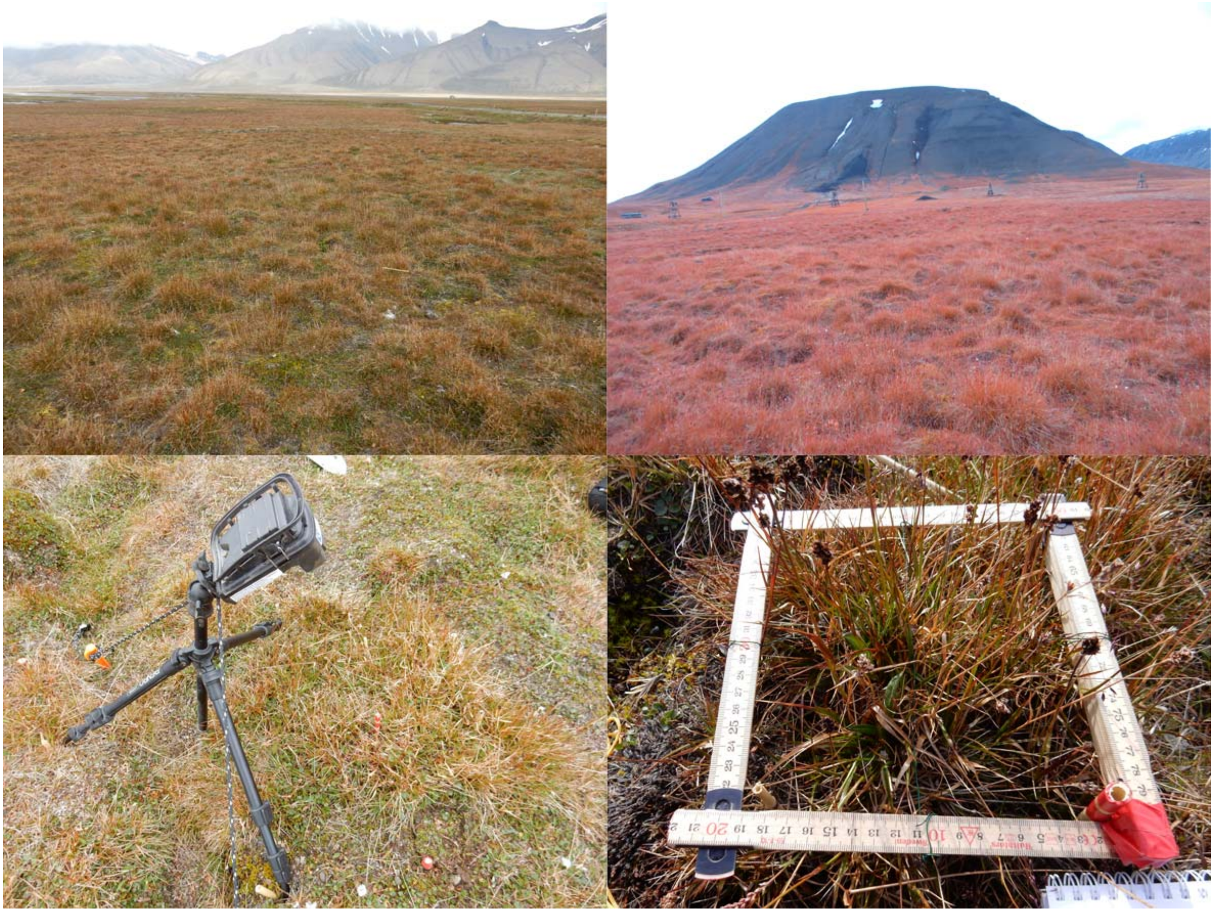

Figure 6. Luzula site LP01. Showing the Luzula site with RGB and NDVI cameras, and placement of time-laps camera and one of the permanent sites.

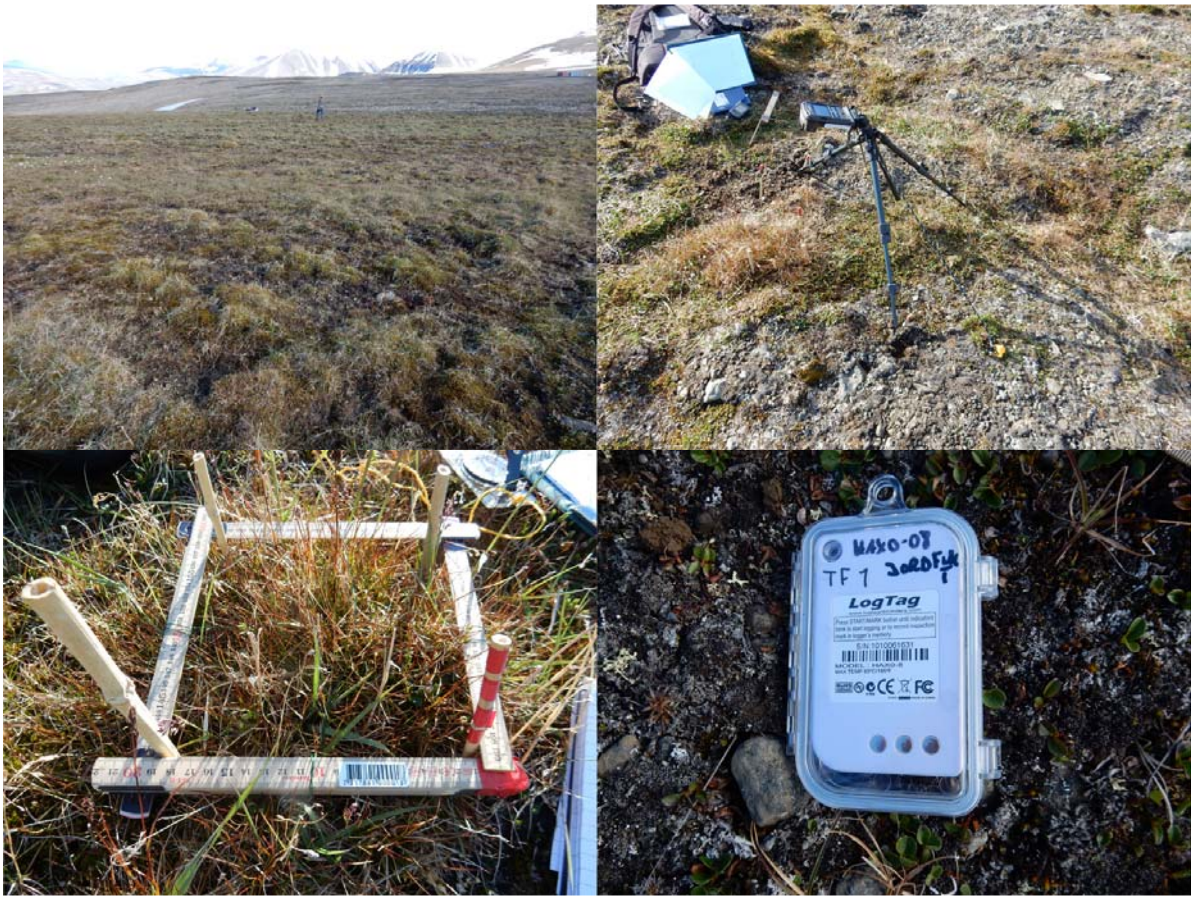

Figure 7. Luzula site LP02, showing the sites, the time-laps camera and the temperature/moisture logger that was dig down.

LP-01 Luzula site
Between Endalen and Todalen, closest to Endalen, eight permanent plots have been established in *Luzula* heath (Figure 4 and 6). The site also has time-laps camera and temperature logger.

LP-02 Luzula site
East side of the main road to Gruve 7 (Figure 4 and 7). Eight permanent plots have been established. The site also has time-laps camera and temperature and moisture sensor.

LP-03 Luzula site
A site north of Tredalshytta (Figure 4). Only destructive samplings in 2015, however, sites are located, and permanent plots is planned to be established in the 2016 season.

4.3 TIME-SERIES OF HIGH RESOLUTION SATELLITE DATA

The main aim is to develop a cloud-free interpolated time-series over Adventdalen from Landsat 8 data for the years 2014 and 2015, which then can be compared with the plant productivity measurements established in the valley (Figure 4). Landsat 8, in orbit since February 2013, uses a scanner with pushbroom technology where the images are collected by two sensors: The Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). With 30m pixel resolution, the satellite has repetition cycle of 16 days at equator. However, the poleward convergence of the Landsat orbits allows for a better temporal resolution at polar latitudes. All the paths 22-29 and 211-218, within row 3-4 or 240-241 on Landsat 8 data cover our study area of Adventdalen valley and data are obtained with an almost daily acquisition frequency. Therefore, Svalbard is well suited for simulate the high temporal resolution of the forthcoming Sentinel-2 data (launched in June 2015, but only limited data available yet). However, data from the different paths of Landsat 8 are recorded at different times of the day, making the calibration more challenging. Frequent fog and clouds, dominance of snow and ice, a short growing season, and often scattered vegetation cover, complicates cloud detection in the study area.

Figure 7. Example on Landsat 8 image. Showing central parts of Svalbard, with Adevntdalen valley in the left part.

From May to September 2014, 82 images were available and among these, only a few images resulted cloud-free enough to be included in this study. The data set of 2014 was hence composed by 17 images, with 7-days average interval time acquisition. In 2015, 67 images were processed and 23 of these had some cloud-free areas. Despite the good temporal resolution (5 days) the dataset was compromised by the high cloud presence and a non-homogeneous time gaps during the season. The images from 2014 and 2015 were then converted to top of atmosphere (TOA) reflectance and TOA brightness temperatures. Afterwards the atmospheric contributions from thermal infrared radiance data were removed from the thermal bands, obtaining the surface's temperature in Kelvin.

We detected and applied 21 pseudo-invariant areas, and used it to calibrate the images of different hours of the day. The reflectance average was obtained for each area, and the relationship between bands was modelled through a linear regression.

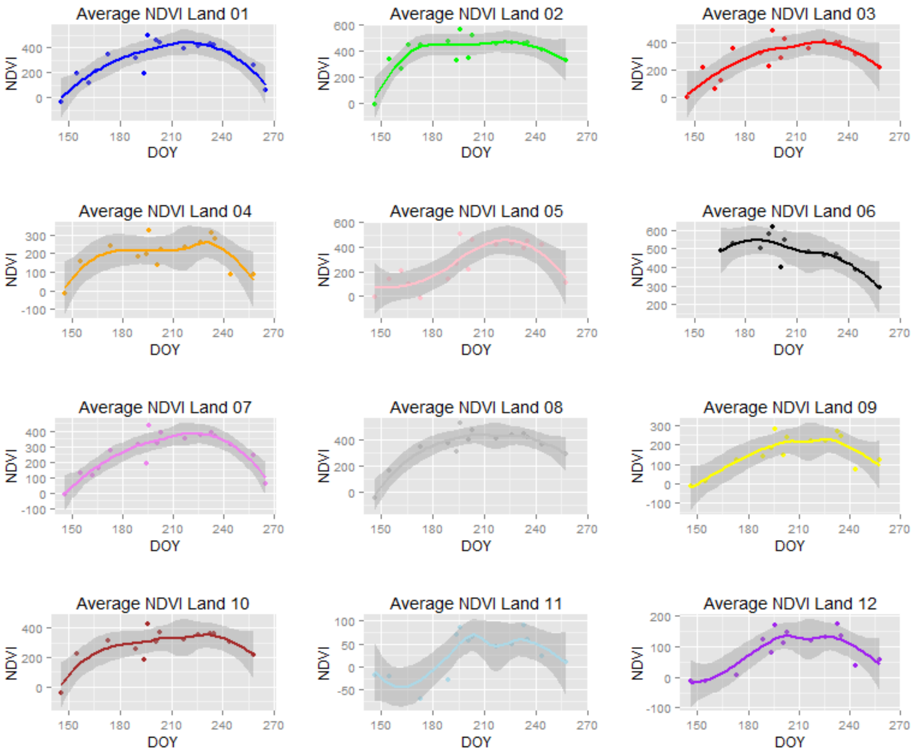

Figure 8. NDVI values from Landsat 8 data for the 2014 season from different vegetation and land cover types in Adventdalen valley. Such studies are done to achieve the best method for mapping the plant productivity for different vegetation types. DOY = Day of year.

For the images of 2014 the clouds cover average was 36.5%, according to the Landsat 8 Automated Cloud-Cover Assessment (ACCA) Algorithm. However, this algorithm does not work well for cloud detections on the archipelago, and the average cloud cover is often much higher. In addition, the Quality Assessment (QA) information and the Cirrus band in Landsat 8 data is only useful for some noise detection on Svalbard. Hence, we also developed altogether nine different cloud detection algorithms for detection of different types of clouds/noise and clouds shadows. On three of the images neither the QA values nor our own cloud detection algorithms detected all the noise in the data and then we manually removed the noise by drawing polygons surrounding the noisy part. This combination of three cloud removing methods (QA/ACCA values, own algorithms, and manual removal), all methods sometimes used on one image, is based on the methods developed for MODIS data on Svalbard (Karlsen et al. 2014). With the cloud-free dataset we then interpolated for the noisy (cloudy) areas based on weighted mean values from the cloud free periods before and after. The dataset was then interpolated to daily data and double-logistic smoothing algorithms on the NDVI values were done.

With the processed cloud-free time-series of daily Landsat 8 data we extracted the NDVI values for the seasons for the different vegetation types in Adventdalen valley (Figure 8) in order to compare the TI NDVI values from the onset of the growth to the time of peak of growth with the field measurements established and the temperature data. We also applied a pixel specific threshold to map the onset of the growing season (Figure 9, Stendardi 2016). However, since we only have one season with field plant productivity data and thereby only three control points it was not enough to up-scale to landscape level, and more years/sites are needed, which is planned for the 2016 season.

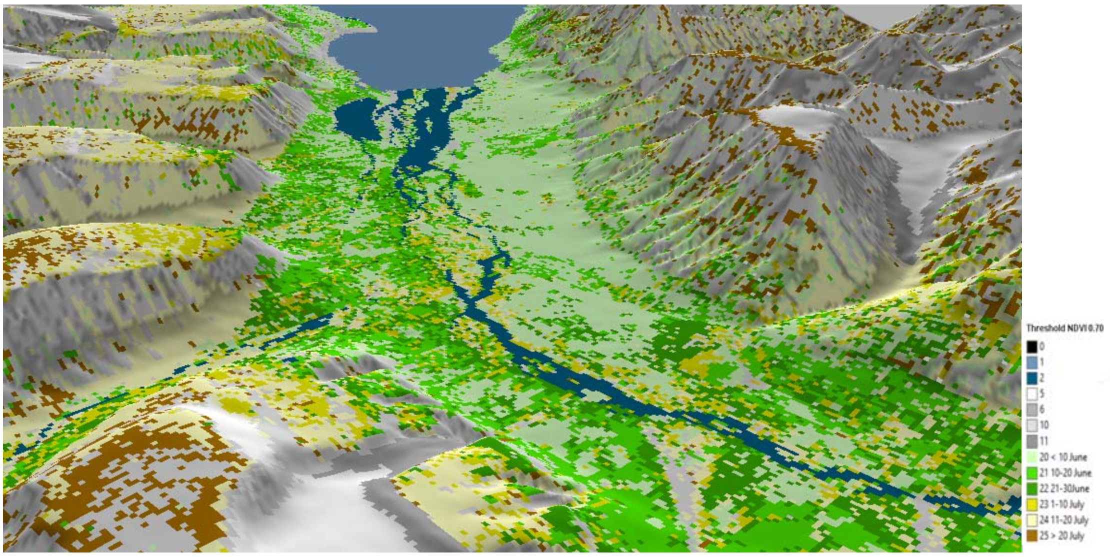

Figure 9. A preliminary version of onset of the growing season in Adventdalen Valley in 2014 based on time-series of Landsat 8 images.

5 SUMMARY

The annual plant productivity supports the populations of reindeers and other herbivores on Svalbard. Given the predicted future warming at such high latitudes as Svalbard, the development of cost-efficient and proper tools for monitoring variation in plant productivity is crucial for our understanding of ecosystem responses to climate change, for management of the reindeer populations, and for estimating the carbon uptake. This study has developed a method to map the annual plant productivity for the years 2000 to 2014 based on MODIS satellite data for the central parts of Svalbard, and has revealed large variation in productivity between the years. The results shows that 2002, 2006 and 2013 were years with higher plant productivity than average, while the summer of 2008 was generally the most extreme year in terms of low plant productivity. This study has also shown that on landscape scale the plant productivity is controlled by the temperature sum from the start of the growth season until the time of peak of the growth. However, this landscape scale study only gives relative values of plant productivity. In order to have more exact values we need to work on species and plant community level. For the Adventalen valley area we have established a relationship between height and weight for two key plant species, and established permanent plots designed to be up-scaled by time-series of high resolution satellite data, and we have developed a processing line for cloud-free time-series of Landsat 8 satellite data. In the coming year this will lead to more exact values of the plant productivity (gram biomass per square meter per year) which can be extrapolated for larger parts of Svalbard.

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