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**Increased GPP in a
high arctic fen
1992–2008**

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Satellites reveal an increase in gross primary production in a greenlandic high arctic fen 1992–2008

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Abstract

Arctic wetlands play a key role in the terrestrial carbon cycle. Recent studies have shown a greening trend and indicated an increase in CO₂ uptake in boreal and sub- to low-arctic areas. Our aim was to combine satellite-based normalized difference vegetation index (NDVI) with ground-based flux measurements of CO₂ to investigate a possible greening trend and potential changes in gross primary production (GPP) between 1992 and 2008 in a high arctic fen area. The study took place in Rylekaerene in the Zackenberg Research Area (74°28' N 20°34' W), located in the National park of North Eastern Greenland. We estimated the light use efficiency (ϵ) for the dominant vegetation types from field measured fractions of photosynthetic active radiation (FAPAR) and ground-based flux measurements of GPP. Measured FAPAR were correlated to satellite-based NDVI. The FAPAR-NDVI relationship in combination with ϵ was applied to satellite data to model GPP 1992–2008. The model was evaluated against field measured GPP. The model was a useful tool for up-scaling GPP and all basic requirements for the model were well met, e.g., FAPAR was well correlated to NDVI and modeled GPP was well correlated to field measurements. The studied high arctic fen area has experienced a strong increase in GPP between 1992 and 2008. The area has during this period also experienced a substantial increase in local air temperature. Consequently, the observed greening trend is most likely due to ongoing climatic change possibly in combination with CO₂ fertilization, due to increasing atmospheric concentrations of CO₂.

1 Introduction

High latitude ecosystems are identified to be susceptible to climatic change through several processes tightly connected to both the regional and global climate systems (Bonan et al., 1995). Arctic wetlands play a key role in controlling the terrestrial carbon cycle, since the prevailing waterlogged, anoxic and cool conditions effectively reduce

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decomposition rates, which favors the formation of peat. Although arctic tundra covers only about 5 percent of the global land area, it holds approximately 12–14 percent of the worlds' total pool of soil organic carbon, and concern have been expressed that the expected changes in climate could cause a decrease in today's sinks and even turn sinks into sources (Post et al., 1982; Oechel et al., 1993). Peat accumulation is primarily governed by the balance between uptake by gross primary production (GPP) and release through decomposition. Changes in the sink strength for high arctic ecosystems are therefore highly affected by responses of these processes to climate variations. Several studies investigating satellites and the normalized difference vegetation index (NDVI) have shown that there is a greening trend in northern ecosystems, indicating an increase in CO₂ uptake (Slayback et al., 2003; Jia et al., 2003; Zhou et al., 2001; Stow et al., 2007; Thompson et al., 2006; Verbyla, 2008; Myneni et al., 1997a). These studies have mainly focused on boreal, sub-arctic and arctic areas and very few studies exist from the high arctic. In the high arctic, temperatures are colder and the growing season shorter than in lower arctic regions. Consequently high arctic ecosystems normally experience higher temperature constraints which presumably make them more sensitive to rising temperatures (Nadelhofer et al., 1997).

A widely applied concept within remote sensing is the approach to estimate productivity by a light use efficiency (LUE) model (Monteith, 1972, 1977) allowing GPP to be estimated from absorbed photosynthetic active radiation according to Eq. (1):

$$\text{GPP} = \varepsilon \cdot \text{PAR} \cdot \text{FAPAR} \quad (1)$$

where ε is the light use efficiency of the vegetation, PAR is incoming photosynthetic active radiation, and FAPAR is the fraction of absorbed photosynthetic active radiation. The ε value was initially considered to be relatively constant, but substantial differences have been found between vegetation types, ages, species composition, and stress level (Goetz and Prince, 1996; Gower et al., 1999) and it is therefore an important parameter to estimate for various vegetation types when evaluating GPP in an area.

Studies in several global vegetation types have shown a near-linear or linear correlation between FAPAR and NDVI and satellite-based NDVI is commonly used to estimate

FAPAR (Asrar et al., 1984; Goward and Huemmrich, 1992; Myneni and Williams, 1994; Myneni et al., 1997b; Fensholt et al., 2004; Olofsson and Eklundh, 2007). However, these studies have focused on crop stands, prairies, semi-arid areas and deciduous and coniferous forests, and an issue of concern is the lack of data when it comes to arctic regions. Yet, as far as we know, it is a relationship that has never been studied for high arctic ecosystems.

In this paper, our aim was to investigate if there as a result of ongoing climate change has been a change in GPP from 1992 to 2008 in a high arctic fen area in North Eastern Greenland. To estimate changes in GPP, we parameterized the light use efficiency model for the peak of the growing season for the dominant high arctic tundra vegetation types. We also correlated FAPAR from the peak of the growing season measured in situ to satellite-based NDVI. The FAPAR-NDVI relationship was combined with the estimated light use efficiency coefficient and applied to satellite data to model GPP for the area, 1992–2008. Finally, the model was evaluated against site-specific measurements of GPP.

2 Materials and methods

2.1 Site description

The study took place in Rylekaerene in the Zackenberg Research Area (74°28' N 20°34' W), located in the National park of North Eastern Greenland. The area is located in the high arctic zone with a local climate in the Zackenberg valley that deviates slightly from the definition of the high arctic climate. Average temperature of the warmest month is 5.8°C, and mean annual temperature is –9°C (Hansen et al., 2008). The Zackenberg valley is underlain by continuous permafrost and the active layer depth ranges between 0.5–1.0 m. The dominant wind direction is N to NNW, except during summer when the prevailing winds are S to SE. Average wind speeds during summer are less than 4 ms⁻¹ (Hansen et al., 2008). The dominant vegetation

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types identified in the Zackenberg valley are fen, grassland, *Cassiope tetragona* heath, *Dryas octopetala* heath, *Vaccinium uliginosum* heath and *Salix arctica* snowbed, which are distributed spatially based on topography, hydrology and soil type (Elberling et al., 2008). Since 1995, extensive ecological, biogeographic, climatic, and hydrological research and monitoring has been carried out in the Zackenberg research area (Meltotte and Rasch, 2008).

In order to describe the vegetation types within the entire Rylekaerene, the dominant vegetation types were registered for every 15 m² (according to a Magellan SporTrakPRO GPS, Thales Navigation, Carquefou Cedex, France) within a 1.4 km² rectangle surrounding Rylekaerene (UTM zone UL 8266853, 512842; LR 8265323, 513757) (Fig. 1). The sampling points were separated into the dominant vegetation types described above, however the fen areas were further divided into continuous fen (flat areas dominated by *Eriophorum scheuchzeri*, *Carex subspathacea* and *Dupontia psilosantha*) and hummocky fen (hummocks dominated by *Eriophorum triste*, *Salix arctica* and *Arctagrostis latifolia*) (Bay, 1998). Non vegetated areas were separated into gravel and water. The size of the sampling points were chosen to match pixels of a satellite image over the Zackenberg valley based on Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) from 25 July 2005. Information about all satellite images used throughout the paper can be found in Table 1.

2.2 Ground-based estimates of FAPAR and its relationship to NDVI

The ASTER image was further used to select two sites within Rylekaerene that enabled FAPAR measurements in a wide range of NDVI values. NDVI was estimated according to Eq. (2);

$$NDVI = (\rho_{NIR} - \rho_{red}) / (\rho_{NIR} + \rho_{red}) \quad (2)$$

Where ρ_{NIR} is the near infrared (NIR) band and ρ_{red} is the red band. (Table 1 for specific bands for each sensor type). The use of NDVI has some advantages; it is independent of pixel heterogeneity, i.e. different vegetation types can result in different configurations

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of ground cover and leaf area index, still FAPAR will be unique (Myneni and Williams, 1994). This validates the use of NDVI in heterogeneous areas with different vegetation types and its use with different satellite sensors data. A total of 13 sampling points were selected in the study sites covering the vegetation types (three continuous fen, two hummocky fen, four grassland, and one each for *Cassiope* heath, *Dryas* heath, *Vaccinium* heath and *Salix* snowbed). To estimate FAPAR, two measured variables are needed; the fraction of intercepted photosynthetic active radiation (FIPAR), and the fraction of ground covered by photosynthetic active vegetation (Hall et al., 1992).

FIPAR was estimated by measuring incoming and reflected PAR every thirtieth second and averaged over ten minutes between 23 June and 5 August 2007 with hemispherical JYP-1000 sensors connected to Minicube loggers. The sensors were placed pointing downwards to measure reflected PAR as close to the corresponding centre of the satellite pixel as possible. The sensors were placed at a height of between 27 and 49 cm above the ground, depending on soil conditions. Less compact soil forced the stand to be pushed further into the ground to prevent it from falling. Incoming PAR was measured by sensors pointing upwards at two locations, and an average value between these was used. To calculate FIPAR, reflected PAR subtracted from incoming PAR was divided by incoming PAR. Data acquired between 18:00 and 9:00 were removed to decrease the impact of low illumination angles.

To estimate the fraction of ground covered by photosynthetic active vegetation, photos were taken of the vegetation underneath the sensors on the 2 and 4 August. The fraction of ground covered by photosynthetic active vegetation on these images was estimated visually using a 0.25 m² square placed on the ground. This fraction was multiplied by average FIPAR estimates from 25 July to 5 August to estimate FAPAR for this period of the growing season, from now on referred to as FAPAR_{max}, since this represents the peak of the growing season. Muskoxen had occasionally overturned sensors and data from these periods were removed.

NDVI was calculated according to Eq. (2) with a Landsat Enhanced Thematic Mapper (ETM+) image from 29 July 2007. All satellite imagery was converted to reflectance

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and atmospheric and terrain corrections were performed with ATCOR 6.1. It has been shown that FAPAR is linearly correlated to NDVI (Asrar et al., 1984; Goward and Huemmrich, 1992; Myneni and Williams, 1994), and a linear regression between NDVI and the ground-based estimates of FAPAR_{max} was fitted. The normality assumption for residuals was checked using a Kolmogorov-Smirnov test. All statistical analyses throughout the analysis were carried out with SPSS 17.0 for Windows. Results of the statistics were regarded as significant if *p*-values were lower than 0.05.

2.3 Ecosystem CO₂ flux measurements

A study site in the centre of the fen areas was chosen to ensure that the main vegetation types were represented within a reasonably small area (Fig. 1). In total, 55 measurement plots were randomly chosen within the different vegetation types; 15 plots for continuous fen, 10 plots each for hummocky fen and grassland, and 5 plots each for *Cassiope* heath, *Dryas* heath, *Vaccinium* heath and *Salix* snowbed. In these plots CO₂ fluxes were measured using the closed chamber technique with an infrared gas analyser (EGM-4, PP-systems, Hitchin, Hertfordshire UK). Measurements were carried out 11 times between 30 June and 4 August 2007. Measurements were distributed over the day so that each individual plot was measured at different times of day (between 10 a.m. and 6 p.m.) over the measurement period. The chamber was 101 dm³ and transparent and the intake and outlet of gas was located at one of the sides 0.15 m and 0.25 m above ground, respectively. To ensure proper mixing of the air and representative sampling from the entire chamber two small fans were located at opposite sides in the upper part of the chamber. A 10 cm collar permanently installed at the base of the chamber was used to minimize air flow under the edges of the chamber.

Immediately before the start of each measurement, the chamber was carefully placed on the ground to avoid disturbance. The change in concentration of CO₂ was recorded continuously for 3 min. Net ecosystem exchange (NEE) was measured with the transparent chamber, and ecosystem dark respiration (ER) was thereafter measured by covering the chamber with a lightproof hood. Soil temperature at 10 cm

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depth, water table depth (for fen vegetation types) and active layer depth were measured in close proximity to each plot during the chamber measurements. Incoming and reflected PAR was measured every 1.3 s within the chamber with hemispherical JYP-1000 sensors and average values were calculated for the same periods as the CO₂ flux measurements.

The CO₂ fluxes were calculated by fitting a line to the concentration change in the chamber over the measurement period. The slope of the line was then used in Eq. (3) for calculating the actual flux.

$$F_c = ((dC/dt) \cdot V_{ch} \cdot P_{atm} \cdot M) (R \cdot T_{air} \cdot A_{ch})^{-1} \quad (3)$$

where F_c is the CO₂ flux, dC/dt is slope of the concentration line, V_{ch} is volume of the chamber, P_{atm} is air pressure, M is molar weight of CO₂, R is the universal gas constant, T_{air} is air temperature, and A_{ch} is the area of ground covered by the chamber. GPP was calculated by subtracting ER from NEE, giving negative values to GPP in this first calculation step. However, since this study focus on GPP and changes in production over time we preferred the view where positive values denote a gain of CO₂ to the ecosystem and effluxes were therefore converted to define GPP as positive and ER as negative. Outliers caused by disturbances were identified using boxplot graphs and removed from the rest of the analysis.

2.4 Estimation of light use efficiency

Three of the 11 ground-based chamber measurements of CO₂, conducted closest in time to the Landsat image acquired 29 July 2007, were chosen for detailed comparisons between GPP and FAPAR_{max}. Incoming and reflected PAR measured inside the chamber were used for estimating FIPAR_{max}, which was multiplied with the area covered by photosynthetic active vegetation within the chamber to calculate chamber-based FAPAR_{max}, from now on referred to as chamber-based to separate it from FIPAR_{max} and FAPAR_{max} measured at the 13 plots with different NDVI (see

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above). There were occasional problems with the sensor calibration, and chamber-based $FAPAR_{max}$ values below 0.8 were considered unrealistic and removed from the analysis. The light use efficiency, ϵ , was estimated by dividing GPP with incoming PAR multiplied by chamber-based $FAPAR_{max}$. Average ϵ_{max} was estimated for all vegetation types. It should be noted that both $FAPAR$ and ϵ varies not only between vegetation types but also over the growing season; chamber-based $FAPAR_{max}$ and ϵ_{max} was therefore used in the following analyses since they represent the peak of the growing season. A one-way ANOVA assuming Tukey's equal variances was performed to test for significant differences between the chamber-based $FAPAR_{max}$ and ϵ_{max} of the different vegetation types.

2.5 The spatial and temporal extrapolation of GPP

In a previous study in Zackenberg, it was shown that carbon exchange of arctic ecosystems are highly governed by timing of the snow melt (Groendahl et al., 2007). To make sure that the analysis focused on the same relative period of the growing season, satellite images were chosen, that were taken approximately the same number of days (± 7) after the snow melt as the Landsat image from 29 July 2007. Snow depth has been measured continuously since 1998 at the climate station (C1) in the centre of the Zackenberg valley (Fig. 1). The day of year (DOY) when snow depth was lower than 10 cm was used as the time of snowmelt. Modeled data from 1989–2004 (Buus-Hinkler et al., 2006) were used to estimate snow cover before 1998. A linear regression was fitted between the DOY of measured 10 cm snow depth and modeled DOY with 18 percent snow cover of the Zackenberg valley for the years 1998–2004 ($R^2 = 0.9766$, $df=5$, $p = 0.00003$), 18 percent was used as a proxy for 10 cm snow depth since the major snow period is considered to end when the snow cover percentage drops below 18 percent according to Buus-Hinkler et al. (2006). The regression line was then used to estimate DOY of 10 cm snow depth for 1992–1997. All satellite images chosen are given in Table 1.

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To be able to compare images between dates and years, the raw satellite imagery were corrected for atmosphere and terrain using ATCOR 6.1. Additionally, 11 points of non-vegetated flat rock surfaces assumed not to vary in reflectance between years were used as reference to compare the reflectance data between years. Lines forced through zero with reference reflectance of all satellite images against reference reflectance 2007 were fitted and used to recalculate reflectance. To avoid edge effects when comparing the satellite imagery with different sized pixels all images were resampled to 1 m using nearest neighbour, and average reflectance for the corresponding 15 m vegetation cover pixels was subsequently calculated for each image.

Equation (2) was used to estimate NDVI, and the linear regression between $FAPAR_{max}$ and NDVI was used to estimate NDVI-based $FAPAR_{max}$ for all images. PAR has been measured hourly between 2002 and 2008 and shortwave irradiance (SW_{in}) has been measured 1996–2008 at C1 (Climatebasis, 2009). The relationship between PAR and shortwave irradiance is site specific and depending on the time of year (Hansen et al., 2008). A linear regression was fitted using data from 25 July to 5 August 2002–2008 to convert SW_{in} to PAR, ($PAR=2.05 \times SW_{in} + 7.41$, $R^2 = 0.991$, $df=2015$, $p = 0.000$). PAR estimates at noon for the day of the satellite images 1998 to 2008 were used as incoming PAR. No radiation data existed before 1998 so for years prior to 1998 the average values measured 1998–2008 on the dates of the satellite images were used instead. We considered this method to be acceptable, because the difference between using average instead of minimum or maximum PAR would change LUE-based GPP at maximum 7.7 percent. Furthermore, the same irradiance was assumed over the entire study area, since it is a small area and the satellite images were recorded on days with clear skies. Estimated ε_{max} for the different vegetation types in Fig. 1 was used together with PAR and the NDVI-based $FAPAR_{max}$ estimates to model GPP from 1992 to 2008. Water and gravel areas were given an ε_{max} of zero. Coverage of the vegetation types is set to be static since we only had estimates from 2007; incorporating a dynamic vegetation change in the LUE model could be a way to improve the analysis in the future.

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2.6 Evaluation of the LUE model

For evaluation of the parameters in the LUE model we used ground-based measurements of GPP from 2007 and a data set with ground-based measurements of GPP from 1998, 1999 and 2000, measured at 6 wet continuous fen plots using the closed chamber technique (Joabsson and Christensen, 2001). For 1999, no satellite images existed in the time window of (± 7) days after the snowmelt, and this year was omitted from the analysis. GPP measurements for 1998 and 2000 were performed between 10 a.m. and 2 p.m. and an average PAR value for this time period was used as incoming PAR. For 2007, incoming PAR measured at the same time as the GPP measurements were used. Subsequently, the LUE model (Eq. 1) was used to estimate GPP for the two measurements closest in time to the satellite image. In the model, estimated ε_{\max} for each vegetation type was used with NDVI-based $FAPAR_{\max}$ and measured average incoming PAR. Average LUE-based GPP for each satellite pixel was evaluated against average measured GPP with a linear correlation analysis using Pearson's correlation. The normality assumption for residuals was checked using a Kolmogorov-Smirnov test.

3 Results

3.1 The relationship between $FAPAR_{\max}$ and satellite-based NDVI

As can be seen in Fig. 2, there was a clear significant linear relationship between NDVI and $FAPAR_{\max}$ ($FAPAR_{\max} = 1.173 \times NDVI - 0.072$, $R^2 = 0.603$, $F = 16.76$, $p = 0.002$, $df = 12$), indicating that plots with lower $FAPAR_{\max}$ had lower NDVI. Further, NDVI from the image 29 July 2007 for the plots where $FAPAR_{\max}$ was measured at was on average 0.56 ± 0.07 . The measurements of $FAPAR_{\max}$ in the respective plots were on average 0.60 ± 0.10 ($df = 12$).

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3.2 Measured daytime CO₂ fluxes and environmental variables

Average GPP during the measurement period ranged from 654.1 to 188.2 mg CO₂ m² h⁻¹ for the different vegetation types, where continuous fen had the highest GPP and *Dryas* heath had the lowest. Average ER ranged from -139.6 to -369.2 mg CO₂ m² h⁻¹ again with *Dryas* heath as the ecosystem with lowest absolute value of respiration and continuous fen as the ecosystem with the highest. Combined, this gave an NEE range from 289.5 mg CO₂ m² h⁻¹ to 22.8 mg CO₂ m² h⁻¹ where continuous fen had the highest uptake and *Cassiope* heath had the lowest (Table 2).

The vegetation types were generally distributed along a small elevation gradient (within a few m) which in combination with a continuous water flow through the fen areas resulted in a strong moisture gradient ranging from continuous fen, hummocky fen and grassland to heath ecosystems (*Salix* snowbed, *Vaccinium* heath, *Cassiope* heath, *Dryas* heath). Although, moisture was not specifically measured for all vegetation types it seemed to affect CO₂ fluxes which gradually decreased with decreased moisture level or increased elevation (Table 2). Water table depths were on average 3.4 cm below the ground surface for continuous fen and 8.2 cm below the surface for hummocky fen (not measured in grassland, *Salix* snowbed, *Cassiope*, *Dryas*, and *Vaccinium* heath since these vegetation types were too dry to find a water table). A similar trend as for moisture/elevation could be seen in the active layer depth in that the elevated/drier ecosystem types had a deeper average active layer than the wetter ecosystems, range 41 cm to 65 cm. Grassland was in-between the wetter and drier ecosystems. Despite the difference in active layer there were no differences between vegetation types in soil temperature (Table 2).

3.3 FAPAR_{max} and light use efficiency for high arctic vegetation types

There were significant differences in chamber-based FAPAR_{max} (on average 0.60) for the vegetation types except for between the continuous fen and the hummocky fen and

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between the different heath vegetation types (*Cassiope*, *Dryas*, *Vaccinatium*, and *Salix* snowbed). Chamber-based FAPAR_{max} was higher for wet vegetation types whereas it was lower for the heath vegetation types (Table 3).

There was a tendency towards differences in light use efficiency, ε_{\max} , between the different vegetation types (Table 3). ε_{\max} was on average 1.83 g CO₂ MJ⁻¹ and it differed with a maximum of 2.29 g CO₂ MJ⁻¹ for the continuous fen to a minimum of 1.11 g CO₂ MJ⁻¹ for the *Dryas* heath. Due to large spatial and temporal variation the differences were however not significant ($F = 1.48$, $p = 0.193$, $df=109$).

3.4 Evaluation of the LUE model

LUE-based modeled GPP was highly correlated to ground-based measurements of GPP (Pearson correlation=0.947, $p = 0.00001$) (Fig. 3). It can be seen in Fig. 3 that for the individual years the LUE-based GPP was somewhat larger than field-measured GPP 1998 and 2007 whereas for 2000 the model fitted well. Over the entire evaluation, the LUE-based GPP was larger (928.2 mg CO₂ m⁻² h⁻¹) than field-measured GPP (720.5 mg CO₂ m⁻² h⁻¹), indicating that the model on average slightly overestimated GPP.

3.5 Investigation of temporal trends in GPP between 1992 and 2008

There was a strong increase in NDVI from 1992 to 2008 for all vegetation types, indicating that there is a greening trend in the Rylekaerene area. There was also a substantial increase in LUE-based GPP 1992–2008 (Fig. 4). The increase was especially dominant up until 2002 whereafter it started to level out. The trend was similar for all vegetation types, even though they differ in GPP. The LUE-based GPP followed the same moisture gradient as the field measurements in that it was gradually decreasing from continuous fen, hummocky fen, grassland, *Salix* snowbed, *Vaccinium* heath, *Cassiope* heath, and *Dryas* heath. A strong decrease in LUE-based GPP could be seen for 2005 (Fig. 4). Average annual air temperature also increased in Zackenberg between

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1992 and 2008 (Fig. 4). Average annual air temperature is based on measurements at C1 for 1996 to 2008 (Climatebasis, 2009). A line between measurements at C1 and measurements at Danmarkshavn (Cappelen, 2007) between 1996 and 2006 was fitted and used for estimating average annual air temperature for the years 1992 to 1995. A fitted line indicates that the average increase in temperature between 1992 and 2008 in Zackenberg was $0.15\text{ }^{\circ}\text{C year}^{-1}$ ($R^2\ 0.708$).

4 Discussion

4.1 Increased GPP for high arctic fen areas 1992 to 2008

Our result showed a strong overall increase in GPP 1992–2008 (ranging between $100\text{ to }400\text{ mg CO}_2\text{ m}^{-2}\text{ h}^{-1}$), which is in agreement with expectations for high latitude ecosystems as the climate is warming (Oechel et al., 2000; Shaver et al., 2000). Correspondingly, average annual air temperature in or in close proximity to the Zackenberg area also increased 1992–2008 (Fig. 4). At low temperatures photosynthesis, as most chemical reactions, is temperature limited, and it increases with temperature (Chapin et al., 2002). Additionally, an increase in temperature prolongs the growing season.

The globally averaged CO_2 concentration at the sea surface has increased on average 1.8 ppm per year since 1992 (Tans, 2009) and a frequent explanation to an increased GPP is an elevated atmospheric CO_2 concentration (Loustau et al., 2001). An increase in the CO_2 concentration has been shown both to stimulate photosynthesis and to restrain photorespiration (Loustau et al., 2001) and it also decreases stomatal conductance, resulting in a decreased water loss due to transpiration (Chapin et al., 2002). Climate change may also results in increased plant growth when plants respond to an increased soil nutrient supply due to warming induced increases in weathering, nitrogen fixation (Sorensen et al., 2006) and decomposition (Robinson et al., 1997). Most natural plant communities today are nutrient limited, giving scarce plant cover. Consequently, an increase in soil nutrients could result in an increased plant cover, as

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indicated by the increased NDVI values seen in this study. Furthermore, the increase in NDVI may point towards a continuous change in vegetation type covering the area supported by the fact that such changes have been reported from other sub-arctic and arctic areas (Oechel et al., 1993; Malmer et al., 2005).

It is however debated how climate change will affect the plants on a long term basis, as it has been shown that the effect of increased CO₂ can be reduced due to changes in moisture and nutrient regimes, and species composition (Loustau et al., 2001; Shaver et al., 2000). As can be seen in Fig. 4, there was a clear increase in LUE-based GPP up until 2000 whereafter it levels out. Ellebjerg et al. (2008) showed a decrease in NDVI 1999–2006 for several high arctic tundra vegetation types in Zackenberg. This was explained both by an earlier timing of snow melt, which reduced water availability during the peak of the growing season, and by an elevation in temperature, which increases evapotranspiration (Ellebjerg et al., 2008). Increased evapotranspiration can result in water loss at high temperatures, which results in drier soils, strongly limiting GPP so that the potential temperature driven increase is missed out. Our results also point to the importance of soil water relations since we found that net carbon gain was largest in the wet fen ecosystem and smallest in the dry heath ecosystems (Table 2).

The year 2005 stands out in comparison to the other years (Fig. 4). It was also the year with the earliest snowmelt (DOY 158, Table 1), and with highest average annual temperature (Fig. 4). The temperature was especially high during wintertime, and there were low snow-cover and several thaw events both during winter and spring (Climate-basis, 2009; Ellebjerg et al., 2008). This indicates the importance of all-year climate for the vegetation.

4.2 CO₂ flux, NDVI, FAPAR_{max} and the light use efficiency of high arctic vegetation

The measured CO₂ fluxes (NEE, ER and GPP in Table 2) were quite large in comparison to other arctic studies but still in the same range (Lafleur and Humphreys, 2008; Nobrega and Grogan, 2008; Soegaard and Nordstroem, 1999; La Puma et al., 2007;

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Arndal et al., 2009). However, some of these studies were on diurnal basis, lowering both GPP and NEE due to low temperatures and low solar angles in comparison to daytime CO₂ fluxes, which were measured in this study.

The linear relationship between NDVI and FAPAR_{max} were shown to be correlated for this high arctic fen area as in accordance with several previous studies for other global land use classes (Myneni et al., 1997b; Olofsson and Eklundh, 2007; Asrar et al., 1984). In Rylekaerene, chamber-based FAPAR_{max} was on average 0.60. We have not found any other studies estimating FAPAR_{max} for high arctic tundra vegetation types, but the fen areas and the grassland had approximately the same values as agricultural and grassland areas studied in the US (Privette et al., 1996; Verstraete et al., 2008) and the heath ecosystems were similar to semi-arid grass savanna (Fensholt et al., 2004; Gobron et al., 2008). Maximum light use efficiency (ϵ_{\max}) in Rylekaerene was low (1.83 g CO₂ MJ⁻¹) in a worldwide comparison; if it is assumed that 0.5 of GPP goes to NPP (Schlesinger, 1997), average ϵ_{\max} would be 0.247 g C NPP MJ⁻¹, whereas a modeled worldwide average is 0.427 g C NPP MJ⁻¹ (Ruimy et al., 1999). However, arctic ecosystems are constrained in their productivity due to extreme temperatures, short growing seasons, low water and nutrient availability and low quantum yield and therefore low in a worldwide comparison. The observed light use efficiency of 0.247 g C NPP MJ⁻¹ was similar to other grassland ecosystems but quite large in comparison to an ϵ_{\max} value for arctic tundra as assumed by global models (Gower et al., 1999). LUE-based GPP was larger than field measured GPP. An explanation to this could be that PAR used in the LUE-based GPP was measured outside a chamber, whereas field-measured GPP measured inside a chamber was constrained due to lower transparency. Another explanation could be that incoming and reflected PAR was measured inside the chamber and may have been influenced by the chamber edges and the collars of the box.

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By applying the light use efficiency model to a satellite data set ranging from 1992 to 2008, we show a substantial increase in GPP in a high arctic fen area during this period. During the same period there has also been a strong global increase in CO₂ concentration and a local increase in air temperature indicating a global change induced increase in GPP. We also parameterized the light use efficiency model for the dominant arctic vegetation types of North Eastern Greenland. FAPAR_{max} was well correlated to NDVI and our investigation shows that NDVI can be used for spatial and temporal extrapolation of FAPAR_{max} in high arctic areas. These findings support the view that NDVI is a useful vegetation index for FAPAR investigations. The light use efficiency model is a simple approach relating ecosystem photosynthesis to absorbed PAR. For this high arctic fen area, the light use efficiency was on average 1.8 g CO₂ MJ⁻¹, which is reasonable for high arctic ecosystems. The LUE-based GPP was well correlated to the field measurements, consequently extrapolating FAPAR spatially and temporally and combining it with the LUE model is a strong tool in the study of global carbon budgets. The light use efficiency model could be used for up-scaling GPP also for larger areas and it revealed a large GPP change in this high arctic fen area 1992–2008.

Acknowledgements. We are thankful to the Swedish research Councils, VR and FORMAS for economical support and to Josefin Tagesson for help with data handling and to Line A. Kyhn for help in the field. We are also grateful to the National Environmental Research Institute, Aarhus University, Denmark and personnel at Zackenberg field station for logistical support.

References

Arndal, M. F., Illeris, L., Michelsen, A., Albert, K., Tamstorf, M. P., and Hansen, B. U.: Seasonal Variation in Gross Ecosystem Production, Plant Biomass, and Carbon and Nitrogen Pools in Five High Arctic Vegetation Types, *Arctic Alpine Res.*, 41, 164–173, 2009.

Asrar, G., Fuchs, M., Kanemasu, E. T., and Hatfield, J. L.: Estimating Absorbed Photosynthetic

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Radiation and Leaf Area Index from Spectral Reflectance in Wheat, *Agron. J.*, 76, 300–306, 1984.

Bay, C.: Vegetation mapping of Zackenberg valley, Northeast Greenland, Danish Polar Center & Botanical Museum, University of Copenhagen, Copenhagen, 29 pp., 1998.

5 Bonan, G. B., Chapin, F. S., and Thompson, S. L.: Boreal forest and tundra ecosystems as components of the climate system, *Climatic Change*, 29, 145–167, 1995.

Buus-Hinkler, J., Hansen, B. U., Tamstorf, M. P., and Pedersen, S. B.: Snow-vegetation relations in a High Arctic ecosystem: Inter-annual variability inferred from new monitoring and modeling concepts, *Remote Sens. Environ.*, 105, 237–247, 2006.

10 Cappelen, J.: DMI Annual Climate Data Collection 1873–2006, Denmark, The Faroe Islands and Greenland- with graphics and danish summary, Technical Report 07-05, Danish Meteorological Institute- Ministry of Transport and Energy, Copenhagen, 23 pp., 2007.

Chapin, F. S., Matson, P. A., and Mooney, H. A.: *Principles of Terrestrial Ecosystem Ecology*, Springer, New York, 43 pp., 2002.

15 Climatebasis: The Zackenberg Database, available at: <http://zdb.dmu.dk>, 2009.

Elberling, B., Tamstorf, M. P., Michelsen, A., Arndal, M. F., Sigsgaard, C., Illeris, L., Bay, C., Hansen, B. U., Christensen, T. R., Hansen, E. S., Jakobsen, B. H., and Beyens, L.: Soil and Plant Community-Characteristics and Dynamics at Zackenberg, in: *Advances in Ecological Research-High Arctic Ecosystem Dynamics in a Changing Climate*, edited by: Meltofte, H., Christensen, T. R., Elberling, B., Forchhammer, M. C., and Rasch, M., Academic Press, 223–248, 2008.

20 Ellebjerg, S. M., Tamstorf, M. P., Illeris, L., Michelsen, A., and Hansen, B. U.: Inter-Annual Variability and Controls of Plant Phenology and Productivity at Zackenberg, in: *Advances in Ecological Research-High Arctic Ecosystem Dynamics in a Changing Climate*, edited by: Meltofte, H., Christensen, T. R., Elberling, B., Forchhammer, M. C., and Rasch, M., Academic Press, 249–273, 2008.

25 Fensholt, R., Sandholt, I., and Rasmussen, M. S.: Evaluation of MODIS LAI, fAPAR and the relation between fAPAR and NDVI in a semi-arid environment using in situ measurements, *Remote Sens. Environ.*, 91, 490–507, 2004.

30 Gobron, N., Pinty, B., Aussedat, O., Taberner, M., Faber, O., Melin, F., Lavergne, T., Robustelli, M., and Snoeij, P.: Uncertainty estimates for the FAPAR operational products derived from MERIS – Impact of top-of-atmosphere radiance uncertainties and validation with field data, *Remote Sens. Environ.*, 112, 1871–1883, 2008.

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- Goetz, S. J. and Prince, S. D.: Remote sensing of net primary production in boreal forest stands, *Agr. Forest Meteorol.*, 78, 149–179, 1996.
- Goward, S. N. and Huemmrich, K. F.: Vegetation canopy PAR absorptance and the Normalized Difference Vegetation Index: an assessment using the SAIL model., *Remote Sens. Environ.*, 39, 119–140, 1992.
- Gower, S. T., Kucharik, C. J., and Norman, J. M.: Direct and Indirect Estimation of Leaf Area Index, fAPAR, and Net Primary Production of Terrestrial Ecosystems - a real or imaginary problem?, *Remote Sens. Environ.*, 70, 29–51, 1999.
- Groendahl, L., Friborg, T., and Soegaard, H.: Temperature and snow-melt controls on interannual variability in carbon exchange in the high Arctic, *Theor. Appl. Climatol.*, 88, 111–125, 2007.
- Hall, F. G., Huemmrich, K. F., Goetz, S. J., Sellers, P. J., and Nickeson, J. E.: Satellite Remote Sensing of Surface Energy Balance: Success, Failures, and Unresolved Issues in FIFE, *J. Geophys. Res.*, 97, 19061–19089, 1992.
- Hansen, B. U., Sigsgaard, C., Rasmussen, L., Cappelen, J., Hinkler, J., Mernild, S. H., Petersen, D., Tamstorf, M. P., Rasch, M., and Hasholt, B.: Present-Day Climate at Zackenberg, in: *Advances in Ecological Research-High Arctic Ecosystem Dynamics in a Changing Climate*, edited by: Meltofte, H., Christensen, T. R., Elberling, B., Forchhammer, M. C., and Rasch, M., Academic Press, 111–149, 2008.
- Jia, G. J., Epstein, H. E., and Walker, D. A.: Greening of arctic Alaska, 1981-2001, *Geophys. Res. Lett.*, 30, 1029–1033, 2003.
- Jobsson, A. and Christensen, T. R.: Methane emissions from wetlands and their relationship with vascular plants: an Arctic example, *Global Change Biol.*, 7, 919–932, 2001.
- La Puma, I. P., Philippi, T. E., and Oberbauer, S. F.: Relating NDVI to ecosystem CO₂ exchange patterns in response to season length and soil warming manipulations in arctic Alaska, *Remote Sens. Environ.*, 109, 225–236, 2007.
- Lafleur, P. M. and Humphreys, E., R.: Spring warming and carbon dioxide exchange over low Arctic tundra in central Canada, *Global Change Biol.*, 14, 740–756, 2008.
- Loustau, D., Hungate, B., and Drake, B. G.: Water, Nitrogen, Rising Atmospheric CO₂, and Terrestrial Productivity, in: *Terrestrial Global Productivity*, edited by: Roy, J., Saugier, B., and Mooney, H. A., Academic press, San Diego, 123–167, 2001.
- Malmer, N., Johansson, T., Olsrud, M., and Christensen, T. R.: Vegetation, climatic changes and net carbon sequestration in a North-Scandinavian subarctic mire over 30 years, *Global*

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- Change Biol., 11, 1895–1909, 2005.
- Meltofte, H. and Rasch, M.: The Study Area at Zackenberg, in: *Advances in Ecological Research-High Arctic Ecosystem Dynamics in a Changing Climate*, edited by: Meltofte, H., Christensen, T. R., Elberling, B., Forchhammer, M. C., and Rasch, M., Academic Press, 101–110, 2008.
- Monteith, J. L.: Solar radiation and productivity in tropical ecosystems, *J. Appl. Ecol.*, 9, 747–766, 1972.
- Monteith, J. L.: Climate and the efficiency of crop production in Britain, *Philos. T. Roy. Soc. B.*, 281, 277–294, 1977.
- Myneni, R. B. and Williams, D. L.: On the relationship between FAPAR and NDVI, *Remote Sens. Environ.*, 49, 200–211, 1994.
- Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G., and Nemani, R. R.: Increased plant growth in the northern high latitudes from 1981 to 1991, *Nature*, 386, 698–702, 1997a.
- Myneni, R. B., Ramakrishna, R., Nemani, R., and Running, S. W.: Estimation of global leaf area index and absorbed par using radiative transfer models, *IEEE T. Geosci. Remote*, 35, 1380–1393, 1997b.
- Nadelhofer, K. J., Shaver, G. R., Giblin, A., and Rastetter, E. B.: Potential Impacts of Climate Change on Nutrient Cycling, Decomposition, and Productivity in Arctic Ecosystems, in: *Global change and arctic terrestrial ecosystems* edited by: Oechel, W., Callaghan, T. V., Gilmanov, T., Holten, J. I., Maxwell, B., Molau, U., and Sveinbjörnsson, B., Springer, New York, 1997.
- Nobrega, S. and Grogan, P.: Landscape and Ecosystem-Level Controls on Net Carbon Dioxide Exchange along a Natural Moisture Gradient in Canadian Low Arctic Tundra, *Ecosystems*, 11, 377–396, 2008.
- Oechel, W. C., Hastings, S. J., Vourlitis, G., Jenkins, M., Riechers, G., and Grulke, N.: Recent change of Arctic tundra ecosystems from a net carbon dioxide sink to a source, *Nature*, 361, 520–523, 1993.
- Oechel, W. C., Vourlitis, G. L., Hastings, S. J., Zulueta, R. C., Hinzman, L., and Kane, D.: Acclimation of ecosystem CO₂ exchange in the Alaskan Arctic in response to decadal climate warming, *Nature*, 406, 978–981, 2000.
- Olofsson, P. and Eklundh, L.: Estimation of absorbed PAR across Scandinavia from satellite measurements. Part II: Modeling and evaluating the fractional absorption, *Remote Sens. Environ.*, 110, 240–251, 2007.

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- Post, W. M., Emanuel, W. R., Zinke, P. J., and Stangenberger, A. G.: Soil carbon pools and world life zones, *Nature*, 298, 156–159, 1982.
- Privette, J. L., Myneni, R. B., Emery, W. J., and Hall, F. G.: Optimal sampling conditions for estimating grassland parameters via reflectance, *IEEE T. Geosci. Remote*, 34, 272–284, 1996.
- Robinson, C. H., Michelsen, A., Lee, J. A., Whitehead, S. J., Callaghan, T. V., Press, M. C., and Jonasson, S.: Elevated atmospheric CO₂ affects decomposition of *Festuca vivipara* (L.) Sm. litter and roots in experiments simulating environmental change in two contrasting arctic ecosystems, *Global Change Biol.*, 3, 37–49, 1997.
- Ruimy, A., Kergoat, L., and Bondeau, A.: Comparing global models of terrestrial net primary productivity (NPP): analysis of differences in light absorption and light-use efficiency, *Global Change Biol.*, 5, 56–64, 1999.
- Schlesinger, W. H.: *Biogeochemistry – an analysis of global change*; 2nd Edition, Academic press, Harcourt Brace & Co. Publishers, London, UK., 1997.
- Shaver, G. R., Canadell, J., Chapin, F. S., Gurevitch, J., Harte, J., Henry, G., Ineson, P., Jonasson, S., Melillo, J., Pitelka, L., and Rustad, L.: Global Warming and Terrestrial Ecosystems: A Conceptual Framework for Analysis, *BioScience*, 50, 871–882, 2000.
- Slayback, D. A., Pinzon, J. E., Los, S. O., and Tucker, C. J.: Northern hemisphere photosynthetic trends 1982–99, *Global Change Biol.*, 9, 1–15, 2003.
- Soegaard, H. and Nordstroem, C.: Carbon dioxide exchange in a high-arctic fen estimated by eddy covariance measurements and modelling, *Global Change Biol.*, 5, 547–562, 1999.
- Sorensen, P. L., Jonasson, S., and Michelsen, A.: Nitrogen Fixation, Denitrification, and Ecosystem Nitrogen Pools in Relation to Vegetation Development in the Subarctic, *Arctic Alpine Res.*, 38, 263–272, 2006.
- Stow, D., Petersen, A., Hope, A., Engstrom, R., and Coulter, L.: Greenness trends of Arctic tundra vegetation in the 1990s: comparison of two NDVI data sets from NOAA AVHRR systems, *Int. J. Remote Sens.*, 28, 4807–4822, 2007.
- Tans, P.: www.esrl.noaa.gov/gmd/ccgg/trends NOAA/ESRL, 2009.
- Thompson, C. C., McGuire, A. D., Clein, J. S., Chapin, F. S., and Beringer, J.: Net Carbon Exchange Across the Arctic Tundra-Boreal Forest Transition in Alaska 1981–2000, *Mitigation and Adaptation Strategies for Global Change*, 11, 805–827, 2006.
- Verbyla, D.: The greening and browning of Alaska based on 1982–2003 satellite data, *Global Ecol. Biogeogr.*, 17, 547–555, 2008.

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Verstraete, M. M., Gobron, N., Ausedat, O., Robustelli, M., Pinty, B., Widlowski, J. L., and Taberner, M.: An automatic procedure to identify key vegetation phenology events using the JRC-FAPAR products, *Adv. Space Res.*, 41, 1773–1783, 2008.

Zhou, L., Tucker, C. J., Kaufmann, R. K., Slayback, D., Shabanov, N. V., and Myneni, R. B.:

- 5 Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999, *J. Geophys. Res.*, 106, 20069–20083, 2001.

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Table 1. Summary of satellite imagery information for the different years; date of satellites imagery, satellite sensors used, range of near-infrared (NIR) bands and range of the red bands, and day of year with 10 cm snow depth for the different years.

Date	Satellite sensor	ρ_{NIR} range (μm)	ρ_{red} range (μm)	DOY with 10 cm snow depth**
8/7/1992	SPOT-2 HRV2	X3 (0.78–0.89)	X2 (0.61–0.68)	176
7/27/1995	Landsat 5 TM	TM4 (0.76–0.90)	TM3 (0.63–0.69)	163
7/31/1998	Landsat 5 TM	TM4 (0.76–0.90)	TM3 (0.63–0.69)	176
7/23/2000	IKONOS	B4 (0.76–0.85)	B3 (0.63–0.70)	165
7/31/2001	SPOT-4 HRV2	X3 (0.78–0.89)	X2 (0.61–0.68)	175
8/2/2002	Landsat 7 ETM+	TM4 (0.76–0.90)	ETM3 (0.63–0.69)	171
7/29/2004	Landsat 7 ETM+*	TM4 (0.76–0.90)	ETM3 (0.63–0.69)	164
7/25/2005	ASTER	B3 (0.76–0.86)	B2 (0.63–0.69)	158
7/29/2007	Landsat 7 ETM+*	TM4 (0.76–0.90)	ETM3 (0.63–0.69)	159
8/9/2008	Landsat 7 ETM+*	TM4 (0.76–0.90)	ETM3 (0.63–0.69)	175

* Images taken when the Scan Line Corrector on Landsat 7 was broken.

** Bold numbers are modelled DOY of 10 cm snow depth from snow coverage by Buus-Hinkler et al (2006) whereas the rest are measured.

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Table 2. Average measured CO₂ fluxes and abiotic parameters for the different vegetation types 21 June–4 August 2007. Average values ± one standard deviation, – means that no measurements were done. NEE is net ecosystem exchange, ER is ecosystem respiration, GPP is gross primary production, and *df* is degrees of freedom.

Vegetation type	Soil temp 10 cm (°C)	Active layer (cm)	Water table depth (cm)	NEE (mg CO ₂ m ⁻² h ⁻¹)	ER (mg CO ₂ m ⁻² h ⁻¹)	GPP (mg CO ₂ m ⁻² h ⁻¹)	<i>df</i>
Continuous fen	7.4 ± 1.3	43 ± 7	-3.4 ± 3.6	289.5 ± 164.4	-369.2 ± 148.0	654.1 ± 250.1	153
Hummocky fen	7.4 ± 1.3	41 ± 9	-8.2 ± 4.2	252.4 ± 225.7	-350.1 ± 138.5	581.1 ± 281.4	107
Grassland	6.0 ± 1.3	47 ± 10		144.1 ± 113.8	-332.1 ± 132.6	475.1 ± 190.0	109
<i>Salix</i> snowbed	8.2 ± 2.1	63 ± 10		36.9 ± 103.5	-207.6 ± 121.1	239.2 ± 127.6	50
<i>Cassiope</i> heath	7.7 ± 1.6	61 ± 9		22.8 ± 76.7	-187.5 ± 92.4	215.0 ± 103.6	53
<i>Dryas</i> heath	8.9 ± 2.1	65 ± 10		38.2 ± 84.0	-139.6 ± 80.2	188.2 ± 94.7	53
<i>Vaccinium</i> Heath	7.6 ± 2.3	58 ± 9		30.5 ± 67.2	-187.4 ± 89.4	217.6 ± 117.5	53

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Table 3. The light use efficiency (ϵ_{\max}) and average chamber-based $FAPAR_{\max}$ for the different vegetation types and for all ecosystems. Average values \pm one standard deviation.

Vegetation type	$FAPAR_{\max}$	ϵ_{\max} (g CO ₂ MJ ⁻¹)	Sample size
Continuous fen	0.72 ± 0.06	2.29 ± 1.12	29
Hummocky fen	0.76 ± 0.04	1.65 ± 0.80	53
Grassland	0.64 ± 0.09	1.72 ± 0.67	26
<i>Salix</i> snowbed	0.34 ± 0.07	2.26 ± 3.93	10
<i>Vaccinium</i> heath	0.43 ± 0.10	1.11 ± 0.89	7
<i>Cassiope</i> heath	0.42 ± 0.04	1.93 ± 1.76	9
<i>Dryas</i> heath	0.33 ± 0.05	1.16 ± 1.45	8
Total	0.60 ± 0.17	1.83 ± 1.36	142

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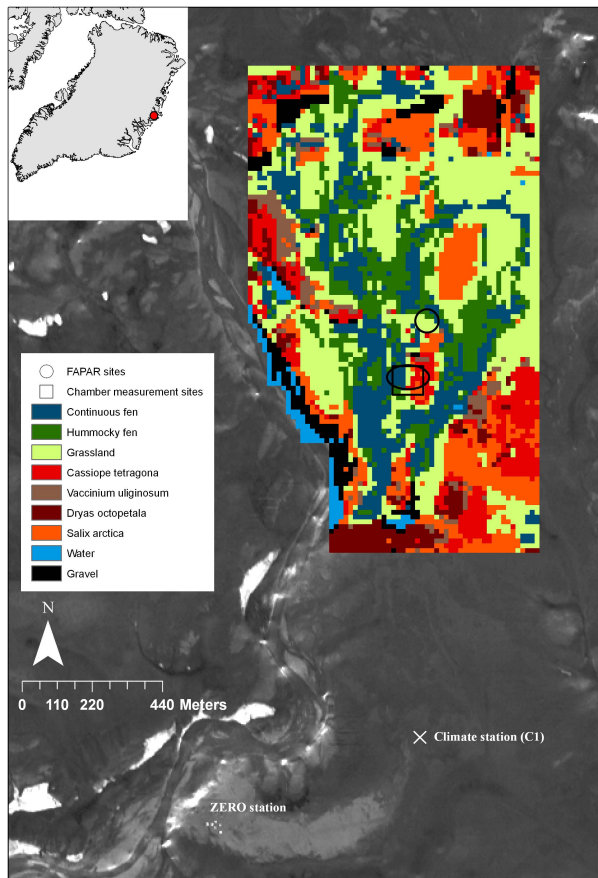


Fig. 1. The Zackenberg valley and the investigation area surrounding the Zackenberg research station (ZERO). The map of the dominant vegetation types estimated in the area surrounding Rylekaerene is superimposed over the area. Climate station (C1) and the Zackenberg research station is marked with crosses. Areas for the FAPAR_{max} measurements are marked with black circles and the area of the chamber measurements are marked with a black rectangle. The red dot on the Greenland map is the location of Zackenberg.

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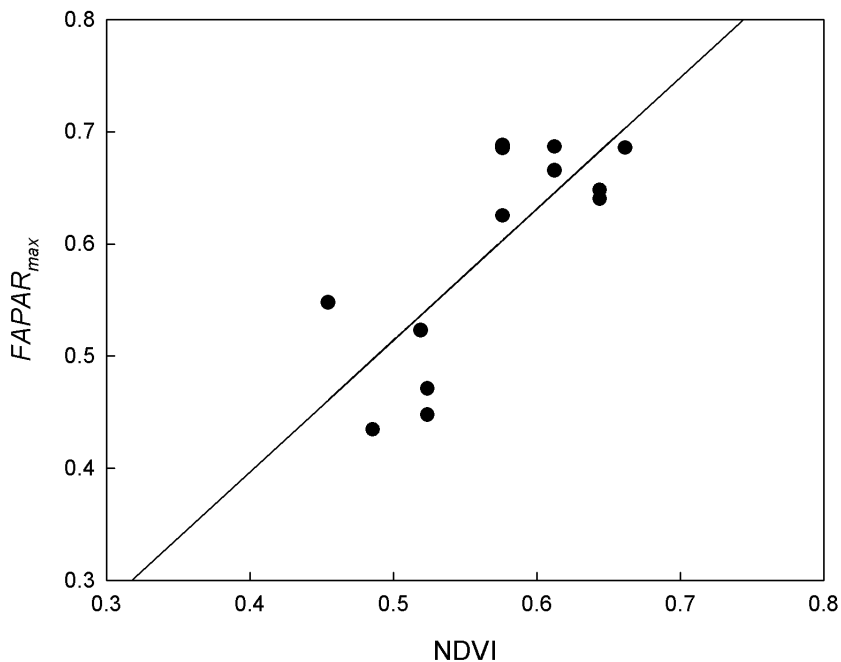


Fig. 2. FAPAR_{max} against satellite-based NDVI from Landsat ETM7+ 29 July 2007. The fitted regression line is $FAPAR_{max} = 1.173 \times NDVI - 0.072$, $R^2 = 0.603$, $F = 16.76$, $p = 0.002$, $df = 12$.

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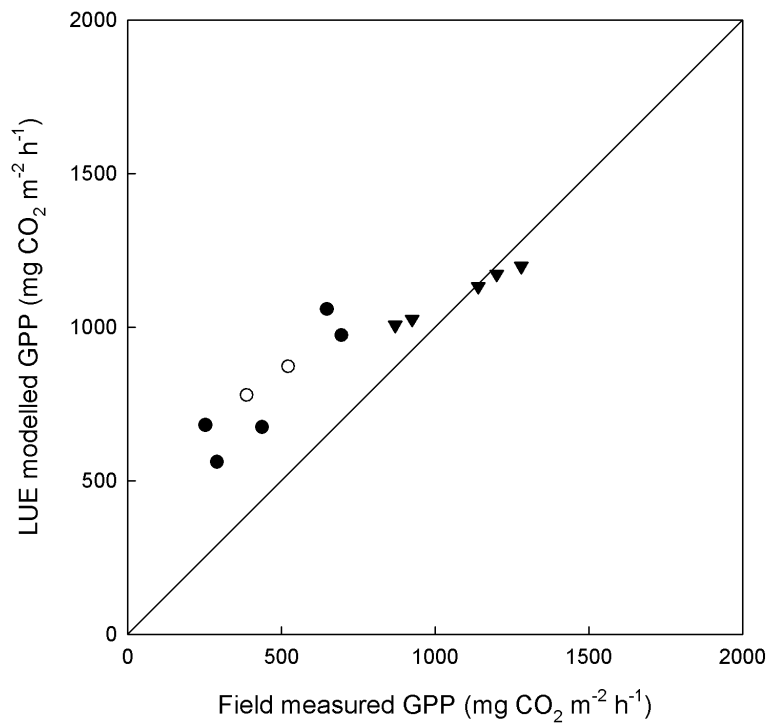


Fig. 3. LUE-based GPP against field-measured GPP, 1998, 2000 and 2007. Triangles are 2000, black dots are 2007 and circles are 1998. The line is the one-to-one ratio.

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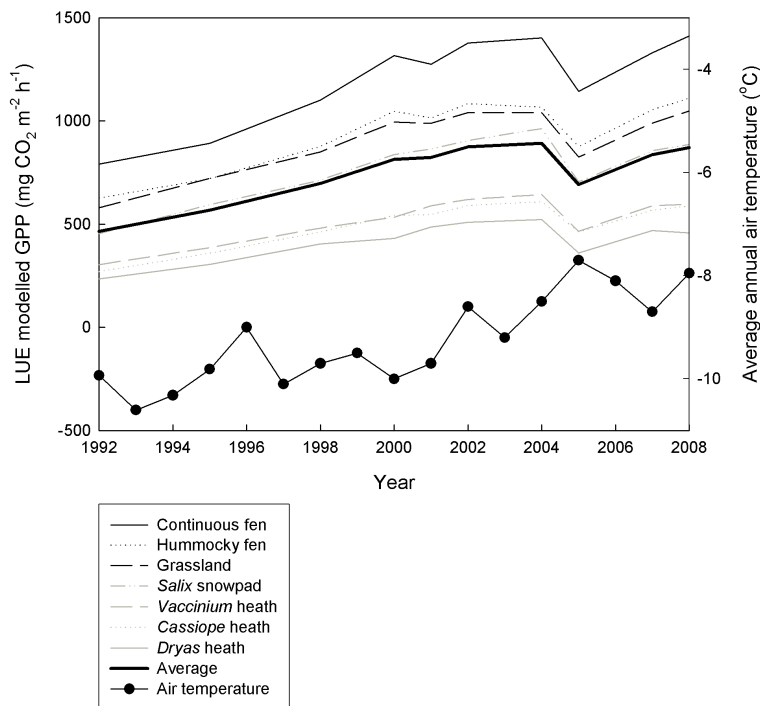


Fig. 4. Graph showing the LUE-based GPP for the different vegetation types and average annual air temperature 1992–2008. Average annual air temperature is based on measurements at C1 for 1996–2008. A line between measurements at C1 and measurements at Danmarkshavn 1996–2006 was fitted. The line was used for estimating average annual air temperature 1992–1995.

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