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Snow cover dynamics and plant phenology documentation using digital camera images and their relation with CO_2-fluxes at Stordalen mire, Northern Sweden

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SNOW COVER DYNAMICS AND PLANT PHENOLOGY DOCUMENTATION USING DIGITAL CAMERA IMAGES AND THEIR RELATION WITH CO_2-FLUXES AT STORDALEN MIRE, NORTHERN SWEDEN

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Degree-thesis in Physical Geography

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Abstract

This report investigates the utilization of digital camera images (DCIs), sensitive in the visible part of the spectrum, for documentation of seasonal and inter-annual variations in snow cover and plant phenology. The DCIs used were transformed to orthographic images (ortho-image) from ordinary oblique DCIs taken between January 2001 and December 2003 at a sub- arctic mire (Stordalen) in northern Sweden. Snow depletion- and ablation curves and a greenness index (GI) together with climatic parameters were produced to examine the relationship with Net Ecosystem Exchange (NEE) measured with eddy covariance technique (EC).

The snow cover length ranged between 183 and 190-days/ year and showed effect on the flux as the driving force on the length of the seasons. The accumulated temperatures during shoulder seasons (spring and fall), especially the fall, are closely correlated to the accumulated carbon fluxes. The length of the summer season is correlated to the accumulated fluxes for the same period. Inter-annual comparisons points out the mire as an increasing carbon (CO_2) sink over the analysed years. The accumulated temperature at Stordalen decreases and becomes warmer during the years of investigation. The creation of a GI was proved functional but a large variation reduces the applicability for vegetation analysis.

The method applied on the data was successful but developing the method would improve the results. By raising the camera, the tilt angel is enlarged and the area of focus improved. This action would make the images usable for a larger area of the mire. If the camera is modified, removing the infrared (IR) filter or installing a new camera with a spectral resolution bridging the IR spectra and preferable with possibilities to save images as raw data (without algorithms and filters and without normalisation for incoming light) would improve the vegetation monitoring.

In spite of this, it is possible to conclude that the mire acts as a larger sinks during long summer seasons. But in the same time, shorter winter seasons produce larger effluxes from the mire. Thus, the shoulder seasons are of high importance for the whole year carbon (CO_2) budget. This work exclude fluxes from CH_4, VOC, and lateral fluxes e.g. DOC from the analysis, as these fluxes generally are important in wetlands carbon budgets, they would if included probably change the (mire) ecosystem from a net sink to a net source.

Sammanfattning

Jordens klimat är ett aktuellt forskningsämne. För att komma fram till resultat som är globalt applicerbara bedrivs forskning för att öka förståelsen och kunskapen om återkopplingsmekanismer mellan klimat och vegetation på många platser runt om i värden och i olika klimatzoner.

Sedan början av 1900-talet har det pågått forskningsstudier (av ekosystemprocesser) i Abisko, norra Sverige och dess omgivning. Den gedigna mängd information som samlats här ger goda möjligheter att komma fram till hur ekosystem reagerar på yttre påverkan och interna förändringar över en lång tidsperiod. Fältarbetet som ligger till grund för min undersökning har gjorts på Stordalsmyren cirka 10 km öster om Abisko. Det är en subarktisk myr med en mosaik av torra förhöjningar och fuktiga sänkor. Under senare år har studierna på Stordalen utvecklats och intensifierats. Sedan några år tillbaka sker kontinuerliga mätningar av koldioxid (CO_2) och visuella förändringar registreras dagligen med hjälp av en digitalkamera.

Syftet med arbetet har varit att undersöka möjligheten att använda bilder från en digitalkamera för att ta fram information om olika faktorers påverkan av ekosystemets kolbalans. Kamerasystemet består av en digital övervakningskamera som automatiskt fotograferar myren en gång per dag klockan 12.00. Bilderna hämtas in och bearbetats i ett program som transformerar de central projicerade bilderna till ortogonal projicerade (Ortho-images), vilket möjliggör avståndsmätningar. Ur bilderna har ett delområde valts ut och klassats som antingen vegetation eller snö. Av denna information har kurvor för snö-avsmältning och ackumulation tagits fram.

För att utvinna mesta möjliga information ur bilderna och göra dem jämförbara har försök gjorts att skapa ett grönhetsindex (GI) som visar utvecklingen hos vegetationen under året. Då kameran registrerar bilderna i tre separata våglängdsband, rött, grönt och blått beräknades avvikelsen av grönt från blått och rött. Kameran är utrustad med ett filter som utelämnar infraröd (IR) strålning, information från IR området hade egentligen varit att föredra då vegetationssignalen är förstärkt i IR regionen av spektrat. Snötäckets tjocklek och varaktighet under vintern påverkar inte utbytet av CO_2 mellan atmosfären och biosfären nämnvärt. Det som har störst inverkan på CO_2-utbytet är våren och höstens längd som varierar mellan åren beroende på hur länge snön ligger. Den finns ett starkt samband mellan den ackumulerade CO_2-fluxen och temperaturen under hösten. Även under våren finns ett samband men det är inte lika tydligt som under hösten. Den sammanlagda CO_2-fluxen under sommaren har ett starkt samband med längden på sommaren. Jämför man åren ser man att ”varma” år tar myren upp (assimilerar) mer CO_2 än vad den avger (respirerar). Med kortare vintrar avges mer CO_2, detta kan ha implikationer på kolbalansen framdeles med ett ändrat klimat.

Då syftet med kameran när den sattes upp inte var fjärranalytiskt är kameran och placeringen av den ej optimalt för just detta ändamål. Vid fortsatt användning av kameran för vegetationsstudier rekommenderas att kameran flyttas i höjdled samt att den utrustas med en IR-känslig sensor för att bättre möjliggöra mer ingående studier av vegetationen.

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1 Introduction

Monitoring the climate in large and small scales require efficient monitoring systems with small demands in power and supervision. When monitored, the data documented needs to be processed in order to extract sufficient information. This study is a combination of methodology study and connecting the documented data to other data measured on the study-site.

Mires in general store large amounts of carbon as peat in environments with cold and wet conditions where the litter production is greater than the rate of decomposition of organic material. The amount of precipitation is greater than the evaporation; this generates a wet anaerobic environment. The sub-artic mires within the discontinuous permafrost zone are partly underlain by permafrost, which limits the water from passing thru the ground when frozen and increases the moisture during thaw (Joabsson, 2001). Sub-arctic mires play an important role in research on earth's climate, as they are sensitive for changes in temperature and precipitation, which affect the carbon balance in the atmosphere. With high water tables, large amounts of methane are emitted but during growing season there are strong uptake of carbon dioxide.

Climate is the average weather for a certain area over a certain time. The climate is a subject of variation due to natural conditions of the area such as mountains, lakes, oceans etc. Climate also varies due to natural seasonal variations or longer variations over time. Climate change is statistically significant variations of the mean state of the climate or its variability, lasting decades or longer. (IPCC, 2001) Climate change may be forced by both natural changes and anthropogenic activity. Currently the climate is warmer than it has been during the last 2000 years.

A current subject of investigation in relation to climate is the global carbon cycle. Carbon dioxide (CO_2) is together with water vapor (H_2O) and methane (CH_4) one of the most abundant greenhouse gases (GHGs) in the atmosphere. Carbon dioxide is more abundant in the atmosphere compared to CH_4 but is 23 times less effective as a GHG on a 100-year basis (IPCC, 2001). The amount of GHGs in the atmosphere is a result of the interaction between biospheric and atmospheric processes and land surface exchange.

As CO_2 is one of the most abundant GHGs in the atmosphere, the knowledge of its life-cycle is important in order to predict more precise future climate scenarios. Currently the world acts as a sink concerning carbon but is by some models predicted to turn into a source around the year 2050 (Cox et al., 2000). The main interaction between living organisms and the atmosphere is the exchange of CO_2 through photosynthesis and respiration. Depending of the state of the vegetation, season, and time of day, the ecosystem acts as either a net- source or a net- sink of carbon depending on respiration and photosynthesis in the ecosystem. Depending on climate and vegetation in an area, the environment (landscape, ecosystem, biome) acts as either source or sink concerning carbon fluxes. By closely monitoring the seasonal, annual and inter-annual variations of different land types, it is possible to understand, validate and narrow down the uncertainties of today's global carbon cycle. Great effort is put into creating models of the Earth's carbon balance to reach for understanding of the current state and enable future predictions. (IPCC, 2001)

Different types of land-cover are characterized by different carbon flux patterns. In the form of peat 12-14% of the terrestrial soil carbon is stored in sub-arctic areas, which only cover 5% of the global land surface (Post et al. 1982). The anaerobic decomposition in the wetlands generates CH_4. Drier soil environments would decrease the CH_4 emissions but increase the release of carbon in terms of CO_2 (IPCC, 2001). Due to the fact that the peat structure in sub arctic mires is underpinned by permafrost are these ecosystems vulnerable and subjected to change even following only small climatic variations (Christensen et al., 2004). At deeper thaw or under total disintegration of the permafrost will the peat structure become unstable and eventually collapse. Depending on the new hydrological status and vegetation composition is the ratio of GHGs likely to change.

Mires in the sub-arctic areas are during a substantial part of the year covered with snow. Many factors determine snow cover dynamics such as temperature and precipitation. The depth of the snow, the density and the redistribution also affects the spatial distribution. Vegetation and micro-topography affect snow accumulation by redistribution of snow by wind (Gray & Male, 1981). One part of this study focus on monitoring snow-cover dynamics. Hence little effort has been put into the actual physics of snow and only the spatial distribution over time has been monitored.

The net flux of CO_2 at Stordalen is registered by an eddy covariance (EC) flux-tower as Net Ecosystem Exchange (NEE). Similar carbon budget investigations, using EC technique have been performed e.g. in Finland by Aurela et al. (2004) and on Greenland by Groendahl et al. (submitted). These studies focus on constraints and drivers of CO_2-fluxes both seasonally and inter-annually. The dataset from Finland was collected over six years. The other study conducted by Groendahl et al. (submitted) at Zackenberg, Greenland, in a high arctic heath ecosystem during five summer-seasons, 1997, and between 2000-2003. There are several other wetland sites with ongoing ecosystem-atmosphere interaction studies in the world including Mere Bleue, Ontario, Canada (e.g. Moore et al., 2002) and Barrow, Alaska U.S.A (e.g. Oechel et al., 1995).

The study-site is the sub-arctic mire Stordalen, Abisko, Northern Sweden that is a mixed mire with dry elevated (ombrotrophic) areas and wetter hollows (minerotrophic). From the start of the project (2000), a camera has been mounted on one of the buildings on the mire to document visual changes over time by taking digital camera images (DCIs). This report aims to closer study the DCIs, transformed into ortho-images, and the information possible to extract from the image-dataset in combination with other data collected on and close to the study site. The focus is to investigate the possibility to use DCIs to monitor the seasonal snow and vegetation changes. Secondly the carbon flux from the mire has been analyzed in relation to the DCI derived data (snow cover dynamics and phenology) and climate data.

1.1 Objectives

The main purposes of this study are:

- Develop an existing method for estimation of the snow cover dynamics at Stordalen mire and evaluate the usage of DCIs and the Ortho-software. Extract seasonal and yearly data and make extracted values comparable. From this information create snow accumulation and depletion curves.
- Examine the relation between CO_2-fluxes from the eddy flux measurements to the extracted data from the DCIs and the seasonal variations metrological and image based.
- Create a greenness index in order to make the growing season comparable without monitoring the IR-wavelengths and study the inter-annual variations in CO_2-fluxes in relation to this.

1.2 Limitations

The data- sets are incomplete due to system failures, mostly caused by power failures and severe weather conditions; damaged images are therefore not used in the analysis. The camera setup was originally not intended for quantified remote sensing purposes. It is therefore not in the ideal position for a study such as the present. It is placed close to the ground with a small angle of tilt, thus the viewing angle become acute to the visible ground limiting the area seen with a acceptable resolution and usable for analysis. The image processing has been time consuming since there are no macro functions in the Ortho-software. As a result, the analyses became limited by time. Since the NEE data is only available processed for three years, the inter-annual comparison is statistically limited. Data from five years at least would have been preferable.

2 Study site - Stordalen

The study site is situated in the far north of Sweden, 10 kilometers east of Abisko at the Stordalen mire. The mire is located close to a series of small lakes between Torneträsk and the road running between Kiruna and Abisko (Svensson et al., 1999) (figure 2.1). Stordalen (68° 21'N, 19° 02'E (lat/long)) is situated on an elevation of about 351 meters above sea level (m.a.s.l) and the long term mean annual temperature (1913-2003) measured at the adjacent research station is –0.7°C (Christensen et al., 2004). The site is sub- arctic mire with a micro-topography of elevated, dry ombrotrophic (low in nutrients) hummocks and wet, minerotrophic (nutrient rich) depressions.

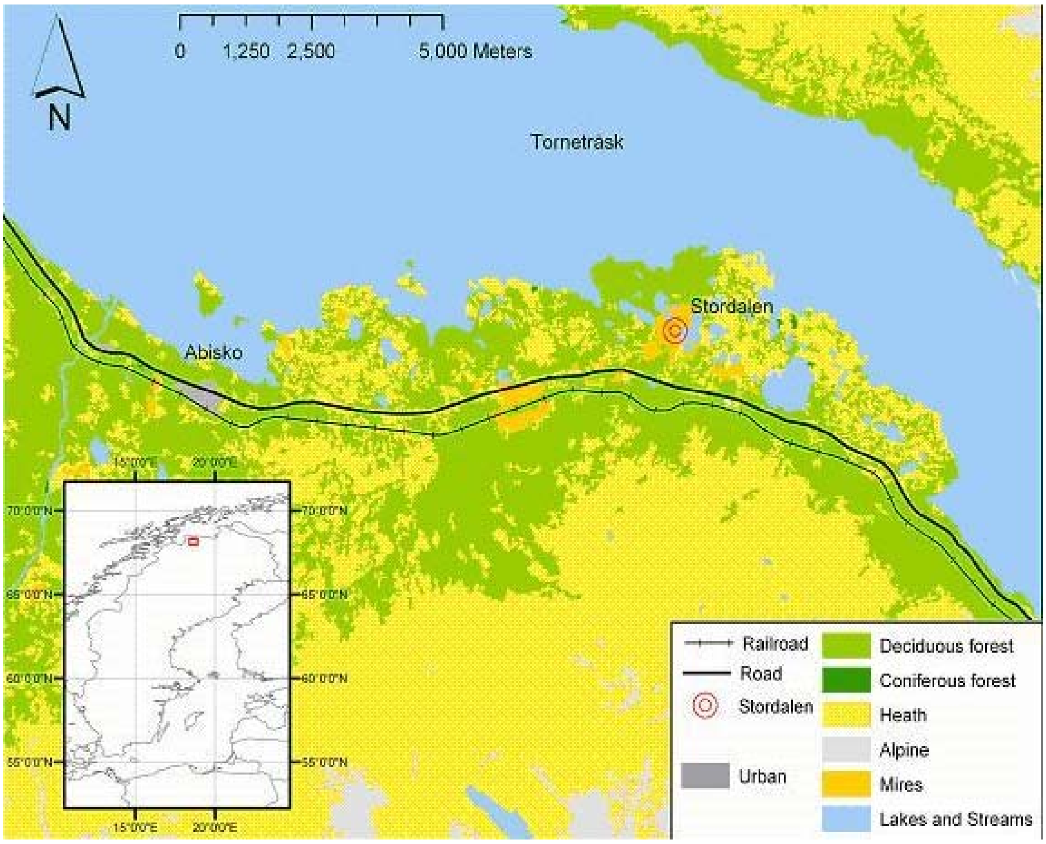

Figure 2.1 Map showing the location of Stordalen in the Abisko area, northern Sweden.

From a compilation of the Swedish ground cover data (SMD) produced within the Swedish CORINE-ground cover data project. The location of Stordalen mire is marked with a red circle. Inserted: Map over Sweden showing the location of the larger map as a small red box.

Abisko is situated 90 km inland from the Arctic Ocean in a rain-shadow situation from the Skande Mountains on the border between Sweden and Norway. The mountains force the clouds entering westward from the Arctic Ocean to rise and precipitate. The air parcel subsequently enters the Abisko region drier than before resulting in a reduced amount of snowfall over the mire.

Intensive studies both at the Abisko Scientific Research Station and at the mire results in profound knowledge of the area and changes over time. Research has been conducted since early 20th century; the first field station in the Torneträsk area was established already 1903. The first flux measurements of CH_4 and CO_2 were conducted at Stordalen during the IBP (International Biological Programme) tundra biome project in the 1970s (Svensson et al., 1999). In recent years, the Stordalen mire has yet again been closely investigated. This time in the context of carbon balance in relation to the warming trend seen globally and in the area since the 1980s, studying both climatic factors and the actual carbon fluxes. Since April 2000, an eddy covariance tower continuously monitors the net exchange of CO_2, H_2O, and energy between the vegetation and the atmosphere on the mire. There are also an automatic chamber system to register releases of CH_4 and VOCs (Volitile Organic Compounds) such as NMHCs (Non Methane Hydro Carbons).

3 Material and methods

Only a short field campaign was required to fulfill the needs for this project. Main focus of the project was to process the raw image data to make it comparable for analysis and in doing this; the method developed for Zackenberg by Hinkler et al. (2002) was used. The Ortho-software was kindly made available for usage by courtesy of Jörgen Hinkler and program developer Kim Have.

3.1 The camera system

As part of the research performed at Stordalen, an Axis 200+ surveillance camera was mounted at one of the buildings to over look the mire in a northwestern direction, (figure 3.1). The exact position of the camera was surveyed by GPS (Global Positioning System) Mangellan SporTrackPRO. This model have a built in augmentation system called WAAS/ EGNOS which produce a better than three-meter position accuracy 95 percent of the time in x and y and a 10 meters in z. The WAAS/EGNOS (Wide Area Augmentation System / European Geostationary Navigation Overlay Service) system is built up by ground stations, reporting the GPS errors to the WAAS/EGOS satellites (Chen & Li, 2004). The signal is corrected and then transmitted to the receivers. This improves the accuracy of the GPS remarkably.

The position of the camera is 75 88 189 N, 16 33 618 E in RT 90 2.5 Gon W 0: -15 (swedish grid) at a height of 354.7 m.a.s.l. The camera is programmed to automatically take photographs every day at noon. This has resulted in a dataset of visual information of the mire since 20th of April 2000.

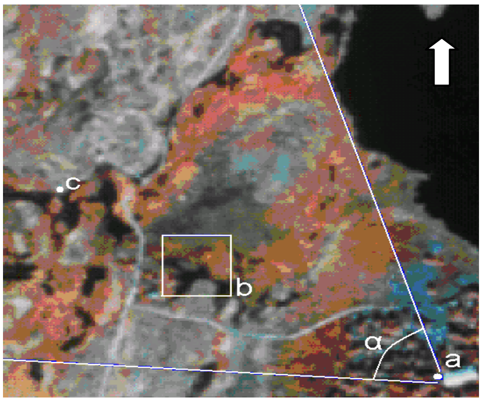

Figure 3.1 Camera position
Schematic figure of the position of the camera (a) and the photographing angle (α) at Stordalen. The square (b) visualizes the window of observation and (c) is the placement of the flux-tower.

The Axis 200+ is a direct digital camera taking 24-bit red, green and blue (RGB), DCIs. The image sensor is a 1/3-inch CCD (charged coupled device) with the resolution of 768 x 582 pixels. The camera is equipped with a quarts low pass filter with infrared (IR) cut filtering (which unfortunately limits the possibilities for vegetation analysis). The camera is equipped with a basic wide-angle lens with the focal length of 5.522mm[1]. The camera system is connected to a 240-camera server with built in web servers for remote monitoring (not in use). The system is programmed to generate a snapshot everyday 12.00AM and store the data on a stationary computer on the site. The complete record of collected images and data is attached in appendix 1.

3.2 Data collection

Collection of coordinates was necessary for turning the oblique images into ortho-images with the Ortho-software (Hinkler et al., 2002). During two days of fieldwork (18-19th of August, 2004), 25 control points were registered by placing a one by one meter, square-shaped white object at different locations within the image-area and through walkie-talkie contact manually take images from the on-site computer connected to the camera. The coordinates (position) and height for the white object was registered through the GPS presented above. The 25 control points were evenly spread out over the study-site with the one condition, to be visible in the image. The data collection also offered the opportunity to get to know the study-site. The map of the control points is attached in appendix 2.

3.3 Image processing

In order to make the data comparable, the images were processed several times to enable extraction of useful information (figure 3.2). The computer software's used are:

- Konvertor
- MatLab 6.5
- Idrisi 32
- GPS-Trackmaker
- GTRANS
- SPSS
- GIMP
- ArcMap
- MS Office NT
- Ortho

[1] Axis 200+ and 240 User's guide, 1999. Axis communications AB. http://www.axis.com 2004-09-05, 10:38AM

3.3.1 Pre-processing

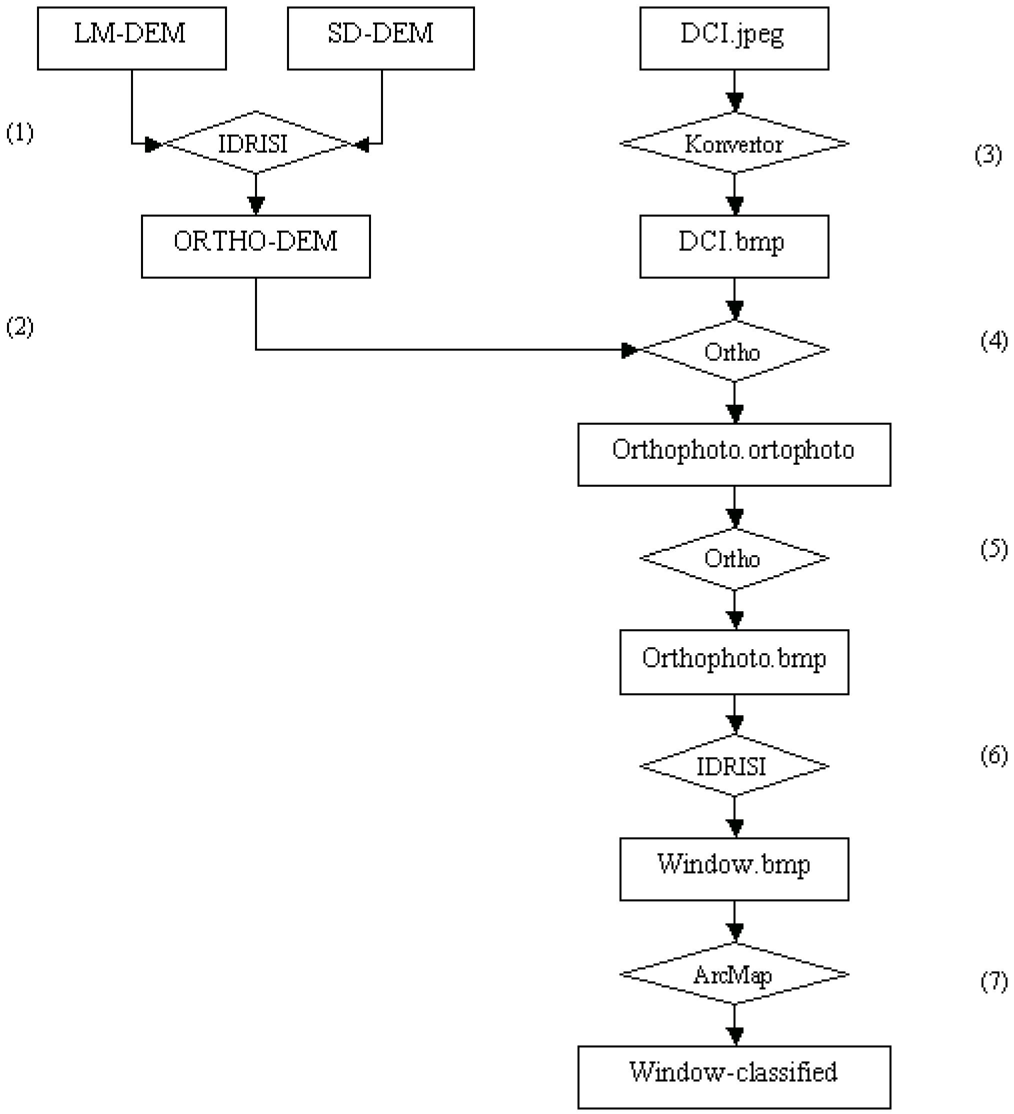

Figure 3.2 Data processing
A complete DEM (Digital Elevation Model) (2) over the area is produced by adding two separate DEMs in IDRISI (1). The DCIs are converted into bitmap files in Konvertor (3). The DCIs are transformed into an ortho-image using the constructed ORTHO-DEM (4) and exported as bitmap files (5). In IDRISI a window of observation is cut out and exported (6). The data from the window is imported in ArcMap and classified (7).

The images are saved as JPEG-files on the on-site computer and collected by burning them onto CDs. Since the Ortho-software only accepts BMP-image files, the entire data set had to be transformed from JPEG into BMP by using the program Konvertor[2]. The

[2] Konvertor – Free 30 day's trial for conversions, Imagespro. http://www.imagespro.com/programs/130/ 2004-08-30, 2:05PM

GPS-coordinates conducted in field was uploaded by GPS-Trackmaker software[3]. From this information, the coordinates in lat/long was exported as a text file and transformed into Swedish grid by using GTRANS.

When the control points were registered on the study-site, they were all registered in separate images. Using GIMP, all the control points were transferred into one image (Figure 3.3). As the program works with a layer function it is possible to add the control points into one layer and apply the point layer to all images separately.

Figure 3.3 Control points
The 25 control points.

Since the position of the camera has been inconstant throughout the years due to snow and strong winds, GIMP was also useful to adjust the images when the camera has moved out of its original position. There is a function to move the layer of control points over the image and by that adjust for such events. Natural objects, visible in the images were used to adjust the control points.

[3] GPStrackmaker – Free download for uploading of GPScoordinates
http://www.gpstm.com/ 2004-08-30, 11:47AM

The Ortho-software demanded a Digital Elevation Model (ORTHO-DEM, figure 3.2) over the area covered by the camera. During the summer 2004, a high-resolution survey using GPS with cm accuracy, RTK technique (Real Time Kinetics) was conducted over the entire mire. Using these data (rawdata grid between 5 and 10 meters) a DEM (nearest neighbor) was interpolated to 1 by 1 meter resolution over the central parts of the mire (RMS 0,21). The high resolution DEM (SD-DEM) was merged to a second DEM (LM-DEM) downloaded from the National Land Survey homepage "Lantmäteriets digitala kartbibliotek" [4] with a resolution of 50 by 50 meters with a geometric standard error of 2.5 m, which covered the rest of visible areas in the images. This was performed by first changing the resolution in the LM-DEM to 1 by 1 meters, the two DEMs were then added by the function CONCAT in IDRISI. The result is a DEM over the entire mire with high spatial resolution with a general low precision in z-led but with higher precision in the central parts. The finalized DEM (ORTHO-DEM) was transferred from IDRISI to a text file, figure 3.2.

3.3.2 Ortho

When using DCIs with central projection, objects in the image are displaced from the center and out. To enable measurements in the images, a differential rectification is performed of the DCIs into ortho-images (a orthogonal projection of objects in an image) by using the software program Ortho (figure 3.2). The scale between the ground coordinate system and the image coordinate system is known by the focal length of the lens. The relation between the coordinate systems can hereby be calculated by six parameters, position of the camera (X_0, Y_0, Z_0) and the orientation of the CCD image plane relative to the ground coordinate system (ω_0, ϕ_0, χ_0). If errors are introduced in original settings it is consistent all through the image series and therefore these sources of errors should be taken into consideration (Hinkler et al., 2000).

The Ortho-software is based on a project-file where to register the information required for the transformation. The information to add to the project file (opened as a notepad file) is (1) the DEM-file, (2) the image to extract the coordinates from and (3) the actual coordinates for the control points. The first time the program is used for a certain site, it is opened with an image where the control points are marked. To register the coordinates

[4] Lantmäteriets digitala kartbibliotek – Sweden
http://www2.geoimager.com/digibib/ 2004-09-10, 3:25PM

in the image, a marking tool is used for marking the tie-points in the image by hand; they then get an image coordinate that is connected to the coordinate of tie-points. These settings are then saved for future image processing.

When the image coordinates are set (control points) and the actual coordinates in the DEM are registered in the documentation file, the image transformation is calculated by entering focal length of the camera-lens and the position of the camera into the program. When marking the points, a default operation in the program computes an inner orientation to calculate the constants of the camera needed to calculate the image, and then an outer orientation is performed. The inner orientation is calculated to determine the actual placement of the projection center (technically) as the outer orientation determines the projection centers relation to objects in the image.

Finally, the transformation of the images is performed to create an ortho-image (step i, figure 3.4). The program is working with three different interpolations: nearest neighbor, bilinear and bicubic. Bicubic interpolation was used after suggestion from Hinkler who by analysis considered it delivering preferable results. Bicublic interpolation calculates an average value from the sixteen nearest pixels (Press et al. 1992). In the program is also a choice to define hidden areas or not. By trying both “define” and “don’t define”, the decision was made not to define hidden areas since it was a faster operation and there was no pronounced difference in the images due to little amounts of hidden areas. The ortho-images are generated as orthophoto- file type but are exported as BMP- files.

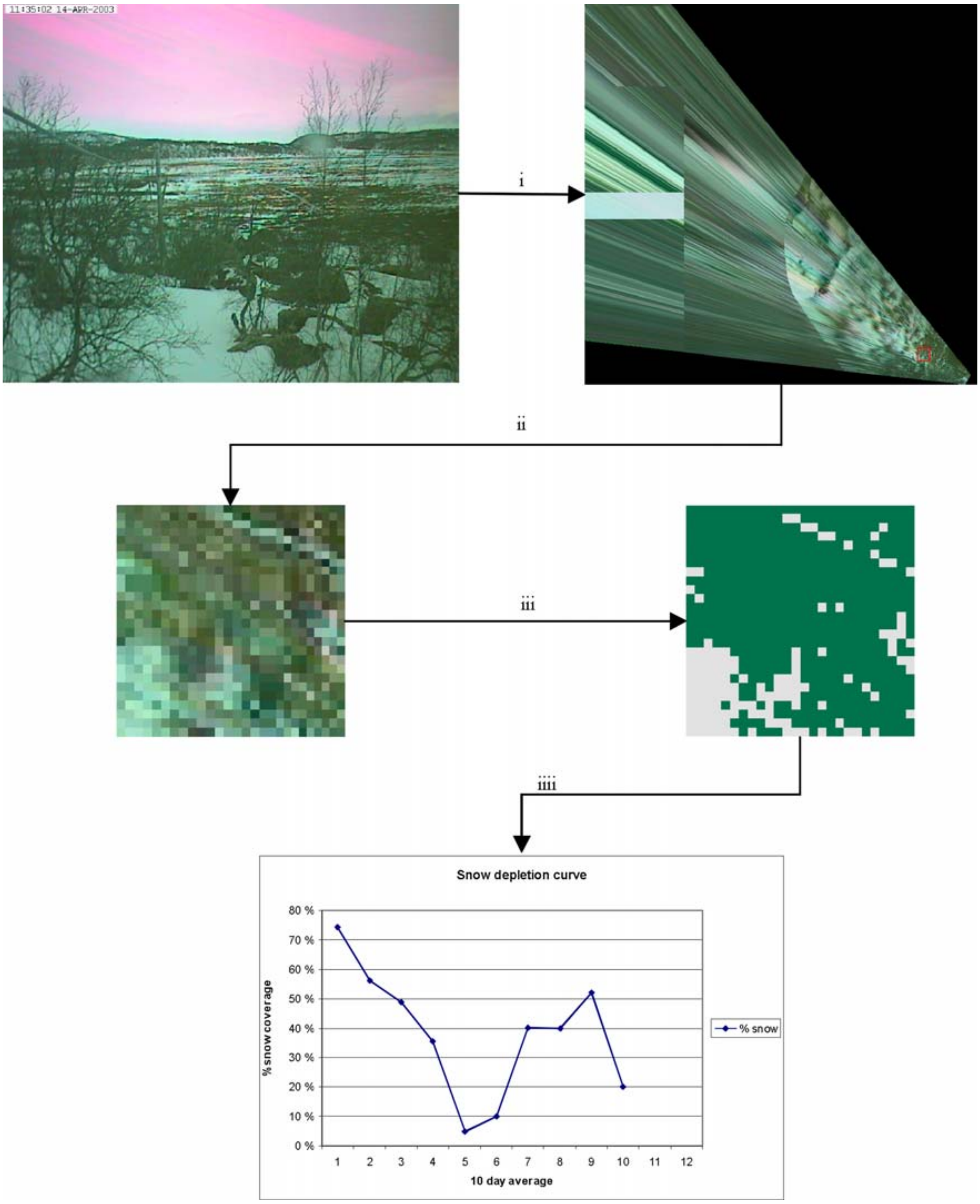

Figure 3.4 Image processing

The different steps in the image processing. Starting with the original DCI transformed into an ortho-image (i). A window of observation is cut out from the ortho-image (ii) and classified in ArcMap (iii). Statistical analysis of the series of images in ArcMap generates snow depletion curves for the separate years (iiii). After Hinkler (2002).

Since the camera is situated close to the ground, the angle generates larger pixels the further from the camera the objects are situated. Therefore calculations were made to determine the distortion of the pixels. Some scenarios of new placements of the camera were also calculated as recommendations for further development of the project. The results of the calculations are displayed in table 4.6.

Physical pixel size on CCD-chip = (width of CCD chip) / (image width (pixels))
Eq.1

Theta = ATAN (elevation of the camera / distance from the camera)
Eq.2

Pixel size across line of sight = (distance from the camera/focal length)*(physical pixel size on CCD-chip)
Eq.3

Pixel size along line of sight = pixel size across line of sight / TAN (theta)
Eq.4

(Personal communication, Hinkler, 2004)

3.3.3 Post-processing

The images were exported from Ortho as BMP-files, and then imported to IDRISI. As the size of the pixels is distorted in both the longitudinal and latitudinal direction out from the camera, a window in the center part with small pixel size and minor distortion was cut out of the images to represent the mire. The window is square shaped, 25 by 25 meters and situated in the center of the image with the Swedish grid-coordinates LL (lower left corner): 16 32 881, 75 88 181 and UR (upper right corner): 16 33 630, 75 88 895.

The images were imported into IDRISI as RST-files (raster-data files). The window was cut out by the function WINDOW and the new images were exported as BMP-files to be able to handle in ArcMap (step ii in figure 3.4). When handling the images in IDRISI, all transformations were registered as IML-files (macro function files in IDRISI) for every month/ every year. These files were then used to run macro for the entire data set, which saved time and cut down the possibility of human failure.

The main concern was to separate snow from vegetation and water. This was possible by extracting the spectral values in the image. Initially this was done in IDRISI but as the number of images added up, a MatLab program was created to extract ten different pixel-values from the series of images and save them as tables in excel. This was applied to create a daily average of the RGB (eq. 5) for each picture without snow.

The images with snow was treated separately and classified as vegetation or snow by using a threshold value. To find the threshold value, images from an early melting period during the spring 2001 day of year (DOY) 13-20 was used for manual classification. To get a mean value (RGB) of the pixel numbers (PN), the mean of the three spectral bands R (red) G (green) and B (blue) was calculated by the formula:

$$RGB = (R+G+B) / 3 \qquad \text{Eq. 5}$$

An average of ten pixels of snow and ten pixels of vegetation in each image was calculated and displayed in figure 3.5 together with standard deviation.

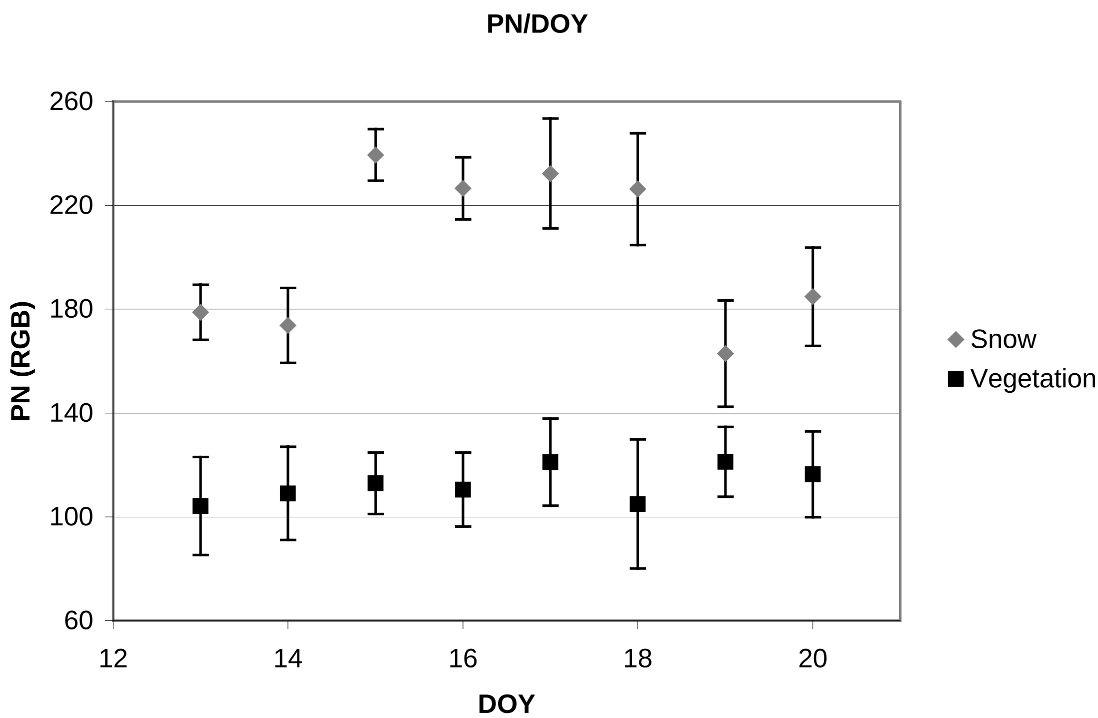

Figure 3.5 Pixel numbers from manual classification, spring 2001.
Average pixel numbers from manual classification during melting period in January 2001.Threshold value in between the two classes was set to PN 140.

By comparing the spectral "curves" of vegetation and snow, a distinct threshold value was found in PN 140 (figure 3.5). This was then used for automatic classification of the images in ArcMap (step iii in figure 3.4). The areas of snow in the classified images were then calculated as a percentage of the entire window in order to be able to create a snow depletion and ablations curves (step iv in figure 3.4) One problem with the classification were the fine line between ice and snow present in the images. In order to limit this error, the original DCIs were studied in a try to determine whether there were ice or snow in the image.

3. 4 Climate and CO_2-flux data

The climate data used in this study is mainly recorded at the site and has been processed by Dr. Thomas Friborg, Institute of Geography, University of Copenhagen. The data has been recorded with 10 minutes interval and recalculated into daily averages. The climate and NEE data has been complemented by data from ANS (Abisko Scientific Research Station). The temperature data is corrected against the ANS data and is therefore complete in the dataset. The Stordalen temperature is affected by the closeness to Torneträsk. The water body acts as a cold source limiting the temperature rise in the surrounding areas. The temperature at Stordalen is approximately 1.3ºC colder at Stordalen than in Abisko (Rydén, 1980).

Some CO_2-flux data was missing during the years but have during 2002 been gap filled by Thomas Friborg. The temperature data from ANS is in one part processed (by Torbjörn Johansson) into growing degree-days (GDD_0) including temperatures at or above 0ºC, and freezing degree-days (FDD) for temperatures below 0ºC. The NEE has been measured form a tower situated close to the window of observation (figure 3.1 at 75 88 276 N, 16 33 474 E (Swedish grid)). The major fetch area (the major uptake area for the flux-tower, limited by wind-direction and speed) is in the east-western wind direction and the major amounts of CO_2-fluxes registered are from a wet minerotrophic area of the mire. The measuring height is 2.9 meters and the equipment is a 3-dimensional sonic anemometer (Gill solent, UK) and an infrared LI-7500 open path CO_2/H_2O gas analyzer[5]. The CO_2-fluxes were calculated of a running mean of 200s. The signals of CO_2 and H_2O were sampled through the analog input channel of the anemometer at 21Hz.

[5] Licor biosciences – Nebraska, USA
http://www.licor.com, 2005-01-20, 4:56PM

The CO_2-fluxes were calculated from axis-rotated vertical wind speeds and raw data was stored in 21Hz (McMillen, 1997 in Friborg et al., 1997). CO_2 and H_2O were corrected for density fluctuation due to temperature and moisture (Friborg et al., 1997).

Thomas Friborg has performed the processing of the flux data. The CO_2-flux is measured by the EC system as NEE, the net sum of the gross primary production GPP (photosynthesis) and total respiration, simply described by equation 6. The total respiration is the sum of the heterotrophic- (maintanance respiration from the vegetation, oxidation of carbon compounds starch, glucose etc) and autotrophic (bacteria etc) respiration.

$$NEE = GPP - R_t \qquad \text{Eq. 6}$$

NEE= Net Ecosystem Exchange GPP = Gross Primary Produciton

R_t = Total respiration from the ecosystem

(Schlesinger, 1997)

3.5 GI – greenness index

When studying vegetation by digital images, the best response on the state of the vegetation and vegetation type is given in the near IR-wavelengths to a notable difference in the reflectance from this part of the spectrum (700-900 nm). The reflectance is dependent on the water content (turgor i.e. osmotic pressure) and the thickness of the leaf (Wastensson, 1993). Since the camera used on Stordalen mire is equipped with a filter removing the IR- wavelengths another way to study the vegetation was required. In the visible part of the spectrum, the reflectance from the vegetation is mainly dependent on the chlorophyll-content in the vegetation. Therefore calculations were performed on the green features in the images.

To my knowledge, no previous work- concerning creating a greenness index (GI) using only broadband information from the visible part of the spectra has been pursued. An initial try to create an index was made by the following calculation (eq.7) based on the pixel numbers in the images.

$$GI = G - ((R+B)/2) \qquad \text{Eq. 7}$$

This calculation strengthens the differences of the green (G) wavelength from the average pixel numbers in red (R) and blue (B). This operation is only performed on days without snow.

3.6 Analysis

The analysis of the data has mainly been performed by statistical processing in excel. By organizing data from separate sources, a database with comparable daily means has been compiled. The data is thereby comparable for several operations. In order to be able to compare different parts of the annual cycle the seasons was split up in two separate ways depending on fixed times of the year (Metrological Based Seasons) and the seasons extracted from studying the DCIs (Image Based Seasons). The CO_2-fluxes are compared both seasonally and inter-annually.

3.6.1 Metrological based seasons (MBS)

The metrological based seasons are based on the metrological year. Metrological seasons are according to the Swedish institute of metrology depending on the temperature. Here the metrological seasons for Kiruna is used[6], where winter is when the daily average temperature is 0°C or below. Spring is when daily average temperatures is rising and is between 0°C and 10°C. Summer is daily average temperatures of 10°C or more, and fall is falling daily average temperatures between 0 and 10°C.

[6] Swedish institute of metrology (SMHI), Sweden
http://www.smhi.se/kund_t/arstider.htm, 2005-04-05 12.35 PM

3.6.2 Image based seasons (IBS)

The image based seasons are governed by the snow cover dynamics at the mire and these seasons are changing over the years depending on the climatic factors. The information on the IBSs is extracted from monitoring the snowmelt in the DCIs. IBS-spring starts at the last day of snow in spring until when the CO_2-flux switches from acting as a source to a sink. The IBS-fall starts when the CO_2-fluxes switches back to source until the first day of snow. The IBS-summer is the growing season between the switches, i.e. the sink-span. The winter is the days of snow cover during the beginning and the end of the year.

4 Results

The aim of the data processing was to create a database with daily averages of snow, CO_2-flux and climate data. The database is displayed in appendix 1. Gaps in the dataset had important effect on the analysis and are presented in table 4.1 (no temperature data is missing due to corrections against ANS-data).

Table 4.1 *Missing data.*

2001	Climate	25-27 & 308-339
	CO_2-flux	4-43 & 307-321
	Snow	
2002	Climate	136-153
	CO_2-flux	42-60, 111-135, 290-302 (gapfilled)
	Snow	28-67
2003	Climate	130-156
	CO_2-flux	1-10 & 293-336
	Snow	1-13

The Metrological Based Seasons for Stordalen are presented in table 4.2. The image based seasons are displayed in table 4.3. Visible here is the shoulder seasons, spring and fall is getting shorter and the summer gets longer from 2001 to 2003. The winter is not varying much over time. Comparing the length of the different type of seasons, the winter and shoulder seasons are longer in the MBS and the summer is shorter.

Table 4.2 *The date, day numbers and length for the meteorological based seasons (MBS).*

		Winter	Spring	Summer	Fall
2001, 2002, 2003	Date	0101-0501, 1010-1231	0501-0617	0618-0815	0816-1009
	Day no	1-120, 283-365	121-168	169-227	228-282
	N	203	48	59	55

Table 4.3 *The date, day numbers and length for the image based seasons (IBS).*

		Winter	Spring	Summer	Fall
2001	Date	0101-0427, 1021-1231	0428-0609	0610-0903	0904-1022
	Day no	1-117, 294-365	118-160	161-246	247-293
	N	189	43	86	47
2002	Date	0101-0424, 1017-1231	0425-0528	0529-0918	0919-1016
	Day no	1-114, 290-365	115-148	149-263	264-289
	N	190	33	115	28
2003	Date	0101-0419, 1019-1231	0419-0519	0520-0922	0923-1018
	Day no	1-109, 292-365	110-139	140-265	266-291
	N	183	31	126	26

The accumulated CO_2-flux during the MBS shows the summer becoming a stronger source from 2001 to 2003 (table 4.4). The fall is turning from a small source in 2001 into an increasing sink 2002 and 2003. During the spring, the CO_2-flux turns from a weak source in 2001 to a strong sink in 2002 and into a weaker sink during 2003. The most interesting temperature difference is during spring 2002, which is really warm.

Table 4.4 *Accumulated CO_2-fluxes (g CO_2 m-2) and temperatures (deg C) for the MBS.*

	MBS-Winter		MBS-Spring		MBS-Summer		MBS-Fall		MBS-year
	CO_2-flux	Temp	CO_2-flux	Temp	CO_2-flux	Temp	CO_2-flux	Temp	Total CO_2-flux
2001	241.88	-1665.36	12.17	183.22	-294.93	604.83	11.8	368.55	-29.08
2002	307.88	-1660.37	-39.12	376.57	-372.84	645.54	-47.56	319.12	-151.65
2003	359.75	-1455.47	-12.29	190.14	-426.34	768.37	-84.81	275.98	-163.69

Looking at the CO_2-flux using the IBS (table 4.5), the summer is becoming a stronger sink during the years of investigation and the winter is becoming a stronger source. Looking at the shoulder seasons, the fall becomes a weaker source and the spring is a weak source becoming a little but stronger during 2002, here the changing lengths of the seasons should be taken into consideration.

Table 4.5 *Accumulated CO_2-fluxes (g CO_2 m-2) and temperatures (deg C) for the IBS.*

	IBS-Winter		IBS-Spring		IBS-Summer		IBS-Fall		IBS-year
	CO_2-flux	Temp	CO_2-flux	Temp	CO_2-flux	Temp	CO_2-flux	Temp	Total CO_2-flux
2001	216.31	-1699.62	21.74	140.29	-333.63	844.01	64.84	206.56	-29.08
2002	298.97	-1668.77	39.6	147.22	-501.02	1208.50	10.59	-6.18	-151.65
2003	343.17	-1428.45	14.93	1.07	-536.64	1194.80	14.85	11.59	-163.69

In order to compare the two types of seasons to each other, correlations were performed with accumulated CO_2-fluxes against accumulated temperatures for each season (figure 4.1). Values for all seasons during all three years gave an significant correlation of R^2= 0,783; p=<0.005.

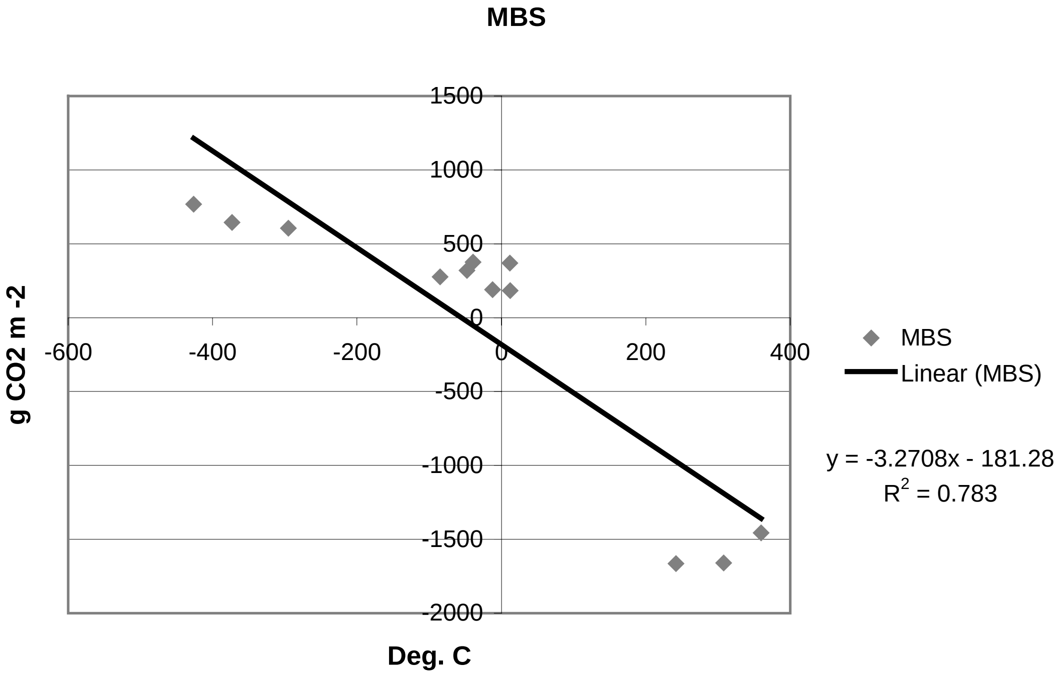

Figure 4.1 Correlation for MBS.
The accumulated seasonal (IBS) temperatures and CO_2-fluxes, values from table 4.3.

When performing correlation analysis on the image based seasons (IBS) (figure 4.2) as in figure 4.1, there is an even more significant correlation than in MBS, R^2= 0,8214; p=<0.005.

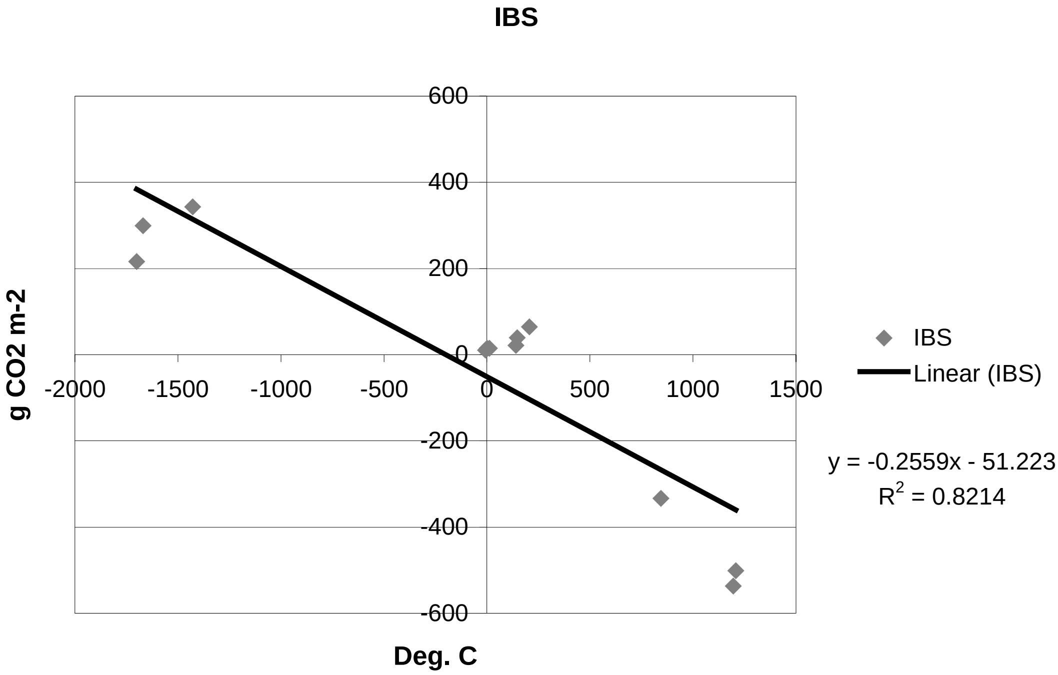

Figure 4.2 Correlations for IBS.
The accumulated seasonal (IBS) temperatures and CO_2-fluxes, values from table 4.4.

The CO_2-flux varies throughout the year. The event of switch occurs different times of the year depending on the balance between photosynthesis and respiration forced by temperature. The approximate time for switches is displayed in figure 4.3. It also shows the annual CO_2-flux 2001-2003 in monthly-accumulated values.

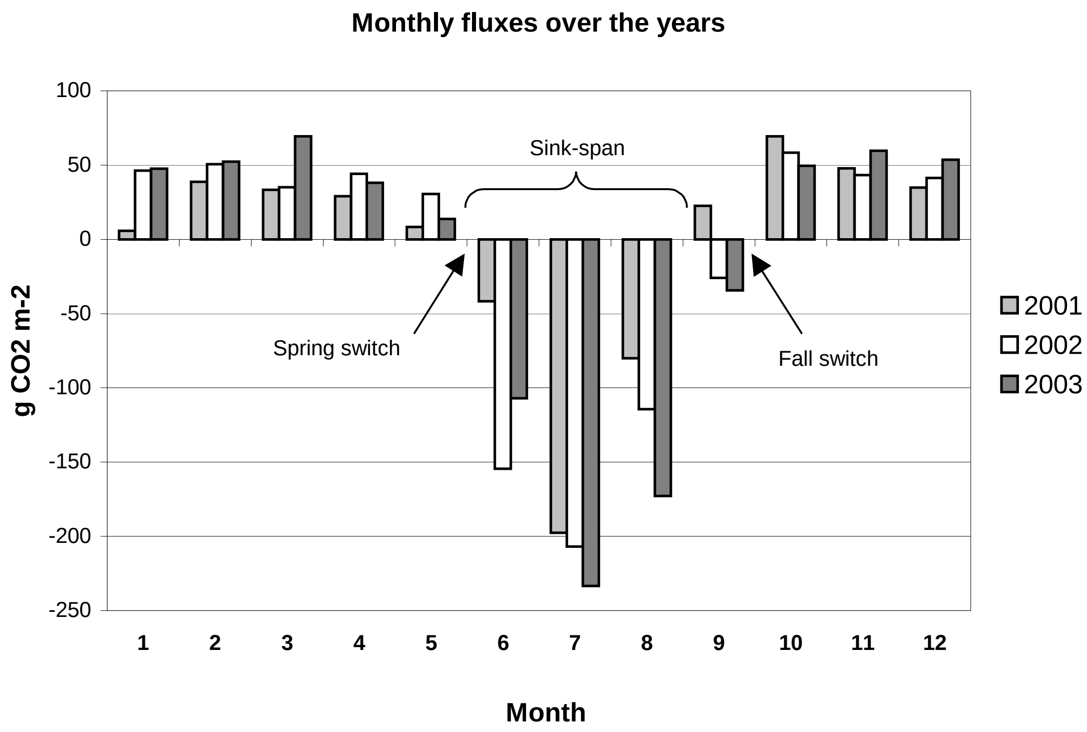

Figure 4.3 Monthly flux variations over the years.
The variation in monthly-accumulated fluxes over the years and the times of switches during spring and fall.

The accumulated temperatures for each year are varying between the years. The year with the smallest variation within the year is 2003. The years 2001 and 2002 have similar variations within respectively year (figure 4.4). The coldest spring is in 2003 but 2001 is the coldest year.

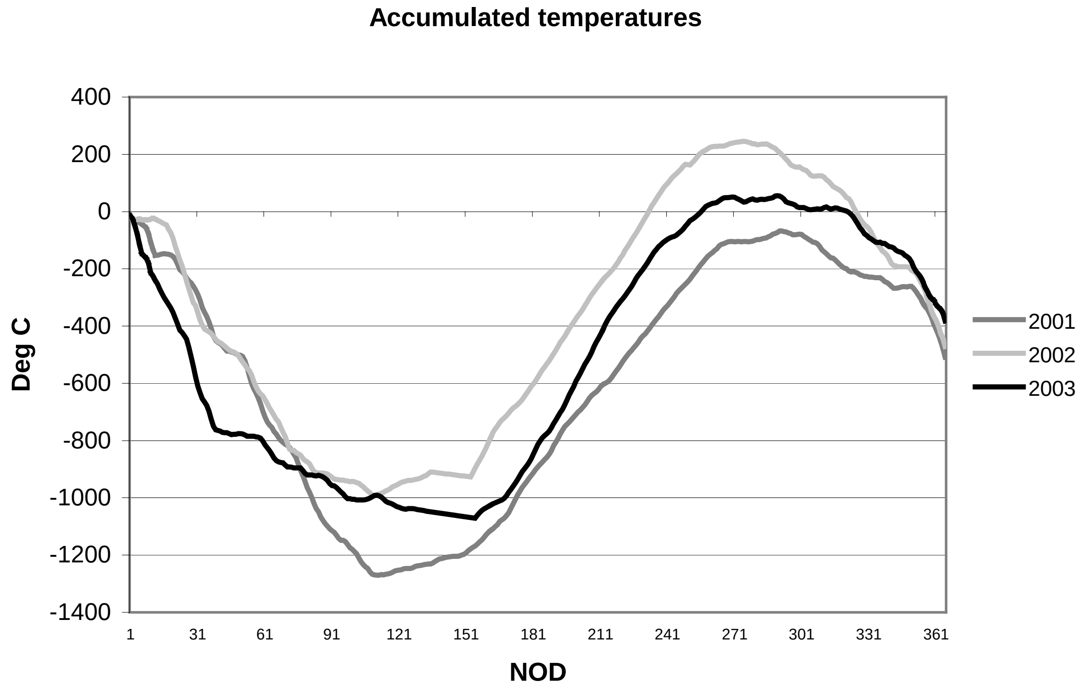

Figure 4.4 Accumulated temperatures
The yearly temperatures accumulated over time (number of days, NOD) for the three years.

To compare the inter-annual differences of the CO_2-fluxes and some of the important factors affecting these are compared in figure 4.5. The total CO_2-flux is turning out to be a stronger sink from 2001 to 2003. The accumulated temperatures are –508.7°C during 2001 but 2003 only half as cold, -221.0°C. This shows that the years get warmer from 2001 until 2003. The GI shows only a small increase over time. There are no significant differences in the incoming radiation (Glob10). Approximately 50 % of the global radiation is within the PAR region (0.46) according to Weiss & Norman (1985) in Monterith & Unsworth (1990).

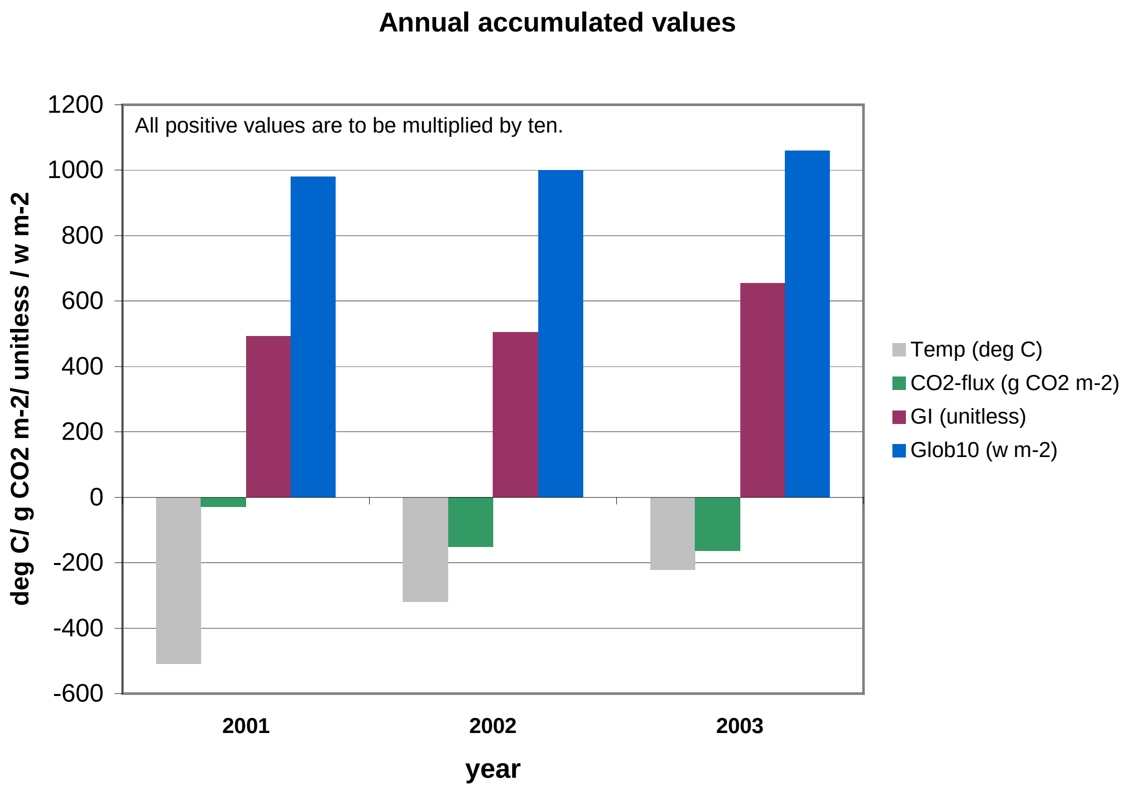

Figure 4.5 Annual accumulated values
The accumulated annual values of different factors and the inter-annual variations.

Studying the accumulated values for the IBS over the years of investigation, the CO_2-fluxes vary in amount seasonally and over time. Figure 4.5 shows the accumulated CO_2-fluxes for the different IBS and the length of the seasons in number of days (NOD) also visualized in the width of the columns. This figure (4.6) shows that the winter period is emitting more CO_2 in 2003 compared with 2001 and 2002. The winter 2001 is considerably shorter and the CO_2 emitted is the lowest. The winter of 2002 was the longest but it did not have the highest amount of CO_2 loss, which (as mentioned) was in the winter of 2003. The spring 2001 emitted 21.74 g CO_2 m-2 over 43 days but in 2002 the spring CO_2-flux is 39.60 g CO_2 m-2 over 34 days, almost twice as much in 9 days less. The spring of 2003 was short with a relatively small release of CO_2. Summer is showing higher uptake in 2003 compared with 2002 and 2001 and the length of the season is also increased. In the summer of 2003, the uptake was almost twice as much over 125 days as in 2001 over 85 days. The fall is a large source during 2001. The emission in 2001 is six times larger than in 2002 and four times larger than in 2003. The fall is almost twice as long 2001 compared to 2002 and 2003.

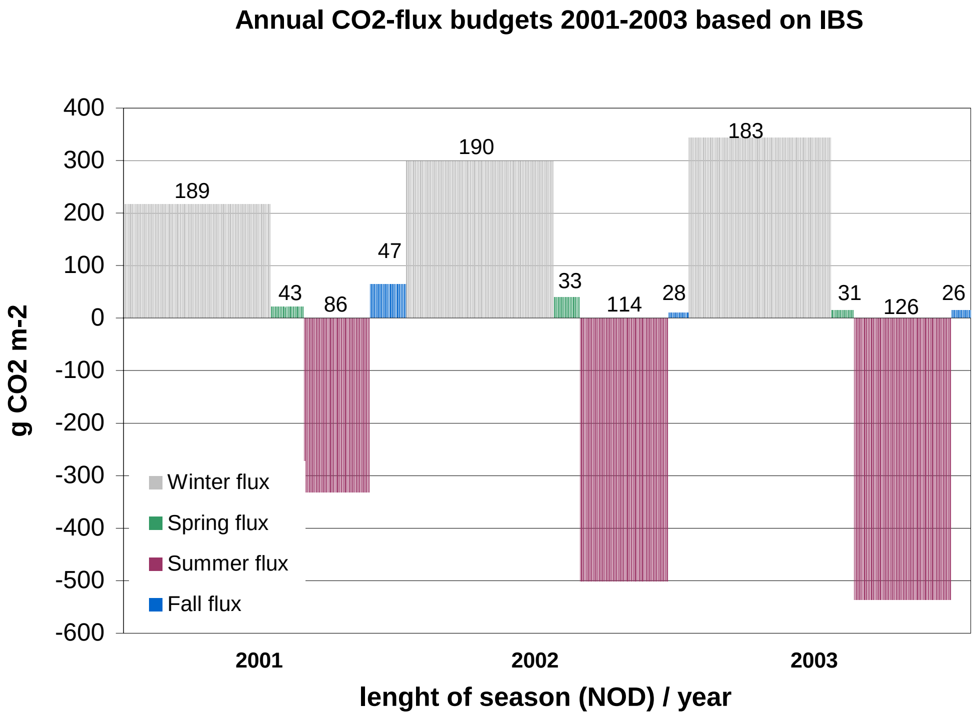

Figure 4.6 Annual CO_2-flux budgets 2001-2003
The annual CO_2-fluxes separated into accumulated flux / season (IBS) and the length of the seasons presented in width of columns and in number of days.

Ablation and accumulation curves based on information extracted from the DCIs are displayed in figure 4.7. The figure shows the amount of snow (1=100% snow-cover) for 2001-2003 and the status of either GDD or FDD. The snow cover is affected by the amount precipitation, wind and of growing degree-days (GDD) versus freezing degree-days (FDD). Figure 4.7 shows not only the difference in snow-cover between the years but also the amount of GDD before total snowmelt and also the total amount of GDD and FDD for the years. The total amount of FDD declined during the study period. Figure 4.7 also visualizes that as soon as there are a period of GDD, the snow melts. There is much less snow during the falls 2002 and 2003.

The dynamics in the snow-cover are notable between the years. The winter seasons in 2001 has a long and consistent snow cover during both spring and fall. During 2002 there was major loss of information (DOY 28-67) caused by dislocation of the camera. Notable for 2002 is the small amount of snow during the fall even though there was a relatively large number of FDD (low precipitation). During 2003 is the GDD (melting periods) more scattered during the cold periods compared to the previous years and the over all amount of snow is rather low compared to the other two years. During 2003, there is a period of melting between DOY 50-65, (February- March) with quick warming and melt-off. This period of change is not visible in the flux measurements. When the snow-cover is completely melted in 2003 there is a period of FDDs DOY 114-122 and the consistent period of GDDs starts about twenty days later than the other years.

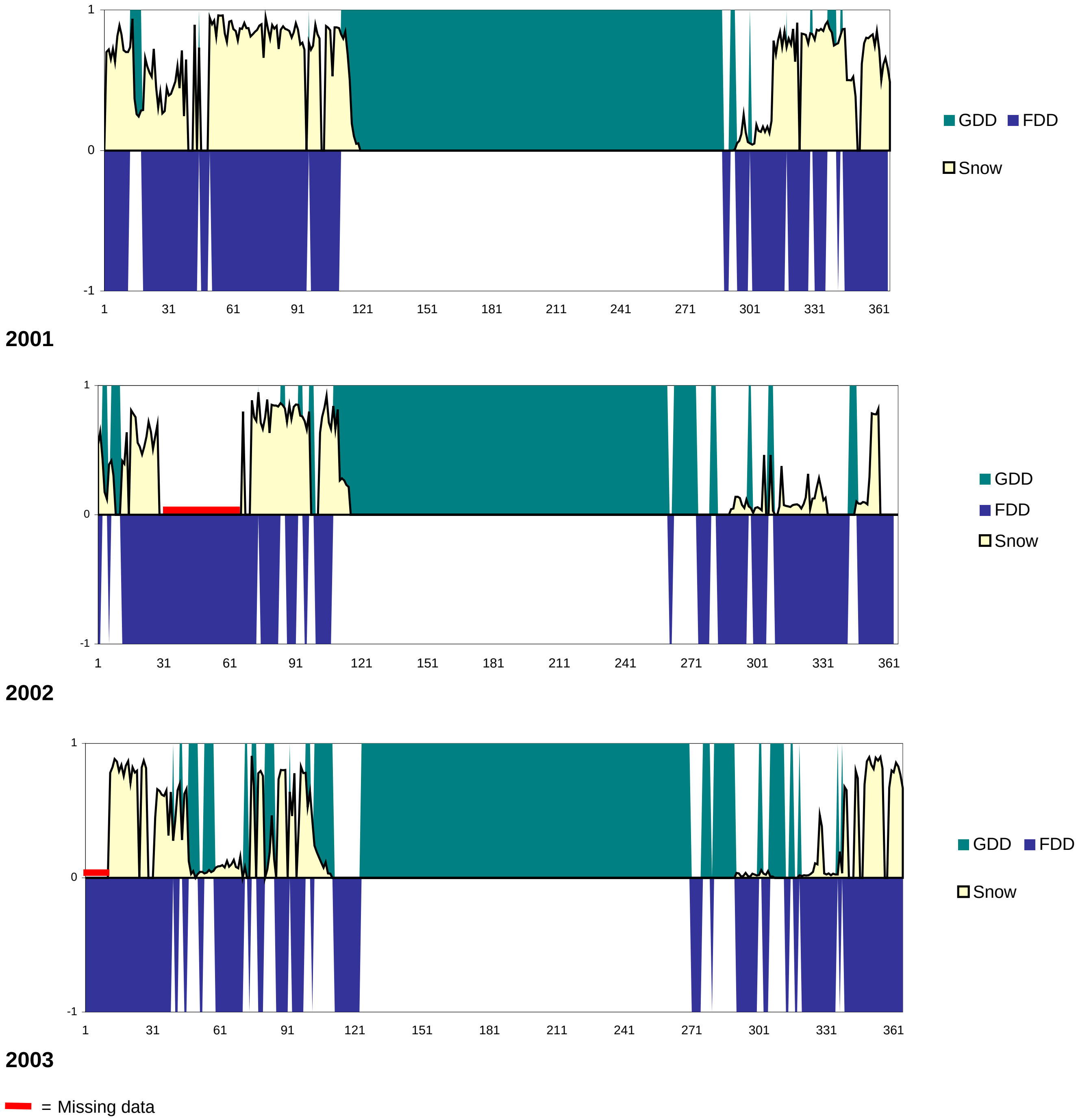

Figure 4.7 Snow and GDD vs. FDD

Comparison between freezing degree-days (FDD) and growing degree-days (GDD) and the amount of snow (1=100% snow-cover).

Figure 4.8 shows the correlation between NEE and GI. The original image is adjusted for incoming light automatically by the camera, therefore the GI is not corrected for any changes in incoming light. The plot between GI and NEE produce a large scatter but the correlation between them is significant, (R^2= 0.5859, p=0.000). The values are calculated as an average for every snow-free day over the three years. The statistical values for each year separately are 2001 (R^2= 0.2465, p=0.000), 2002 (R^2= 0.3364, p=0.000) and 2003 (R^2= 0.4714, p=0.000).

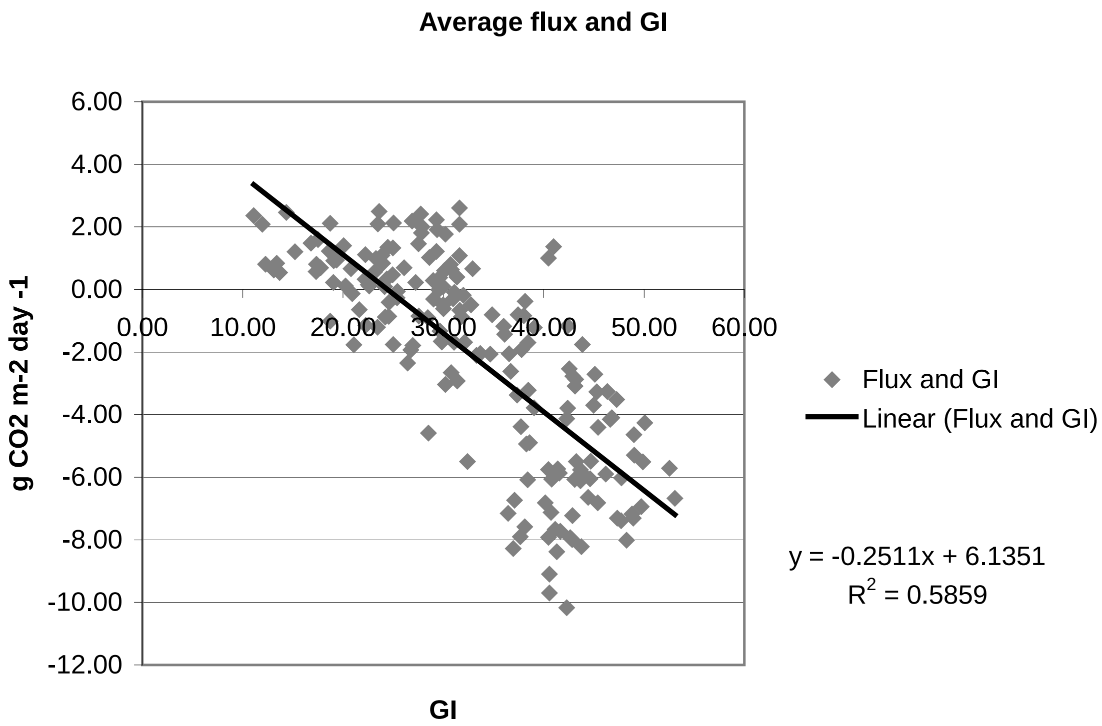

Figure 4.8 Correlations between CO_2-flux and GI
Correlation between CO_2-flux and GI for an average all three years.

The low camera position generates several problems while creating ortho-images from the DCIs. By elevating the camera and thereby reduce the viewing angle of the camera, a more realistic reproduction of the pixels in the ortho-image would be performed. In table 4.6, the distortion of the pixels is presented for the actual height of the camera (height 5m). Three scenarios are accounted for if elevating the camera to a height of 10, 15 and 20 meter.

Table 4.6 *Actual height of the camera and three alternative heights and pixel distortion.*

Distance (m)	Angle (deg)	Pixel Across (m)	Pixel Along (m)	Angle (deg)	Pixel Across (m)	Pixel Along (m)
	Height 5m			Height 10m		
10	26.57	0.02	0.03	45.00	0.02	0.02
20	14.04	0.03	0.12	26.57	0.03	0.06
30	9.46	0.05	0.27	18.43	0.05	0.14
40	7.13	0.06	0.48	14.04	0.06	0.24
50	5.71	0.08	0.75	11.31	0.08	0.38
60	4.76	0.09	1.08	9.46	0.09	0.54
70	4.09	0.11	1.47	8.13	0.11	0.74
80	3.58	0.12	1.92	7.13	0.12	0.96
90	3.18	0.14	2.43	6.34	0.14	1.22
100	2.86	0.15	3.00	5.71	0.15	1.50
	Height 15m			Height 25m		
10	56.31	0.02	0.01	63.43	0.02	0.01
20	36.87	0.03	0.04	45.00	0.03	0.03
30	26.57	0.05	0.09	33.69	0.05	0.07
40	20.56	0.06	0.16	26.57	0.06	0.12
50	16.70	0.08	0.25	21.80	0.08	0.19
60	14.04	0.09	0.36	18.43	0.09	0.27
70	12.09	0.11	0.49	15.95	0.11	0.37
80	10.62	0.12	0.64	14.04	0.12	0.48
90	9.46	0.14	0.81	12.53	0.14	0.61
100	8.53	0.15	1.00	11.31	0.15	0.75

5 Discussion

As the purpose of this research was to study the snow cover dynamics, greenness variations and its relation to fluxes of CO_2 the investigation have shown interesting results with several uncertainties. The method used with the digital camera was successful but some changes may be done in order to achieve better results.

The window of investigation is situated in the wet minerotrophic part of the mire, which lays in the main fetch area of the flux-tower. Due to warming and melting of permafrost, the wet areas are increasing over time, which makes it an important subject of study (Christensen et al, 2004). The Ortho-software used in this study has only been used twice before, in Zackenberg, Greenland 1998-1999 (Hinkler et al., 2002) and in Ny-Ålesund, Svalbard 2002 (Hinkler et al., 2003). In 2002, Hinkler et al. published a methodological study concerning the temporal variations of snow cover and the later work published 2003 included classification of vegetation, gravel and ice in the images. When comparing data from Stordalen mire to Hinkler et al. (2002), it is important to take into account the many differences site characteristics and camera set-up. In both cases of the published research of Hinkler et al., the camera is situated at much higher elevation; 500m in Zackenberg and 474m in Ny-Ålesund. This enables studies over larger areas compared to the low elevation at Stordalen mire. By changing the elevation of the camera at Stordalen, a full analysis over the different vegetation communities will be possible. In spite of the fact of the incompleteness my research show the potential of high temporal resolution and low-cost camera investigations. The advantage of little manual monitoring gives much information with little observation during winter etc.

While using this method, several sources of error occurred. As the camera and program was not intended to work together at the time of set-up they work with different file types. The camera stores the images as jpeg files which compresses the files. In order to use the images in the Ortho-software, they have to be bmp-files. All these transformation between data types may create an error in the data, which is not measurable. As the camera was moved out of its current position several times in the past and no control points were registered at the time, the adjustments in the images have been performed manually. This operation is a second source of error as it is not a measured adjustment. The DEM over the mire has a large RMS error of 0.21 on 1 meter. This is due to steep changes of elevation on the mire on small distances. The steeper areas has been measured more abundant and the large RMS value is introduced in the interpolation process. Since the studied images are taken in the past (2001-2003), there are no possibilities to evaluate the classification of the snow-vegetation classes or presence of ice. This could have been done this year but was limited by time and founds.

Snow influences the layer of permafrost as deep snow layer in early fall prevents the ground from freezing since the snow provides insulation and limits the extent to which cold air penetrate down the peat. The presence of snow in early spring acts the opposite way and prevents the ground from warming when the air heats up (Gray & Male, 1981). For the three years of investigation, there are major differences in snow cover (figure 4.8). 2001 there is a consistent snow cover during both spring and fall. In 2002, there are major losses of information during the spring but during the fall the snow-cover is significantly smaller compared to 2001. The majority of melting events during spring 2003 is caused by repeated periods of positive temperatures (GDDs). The difference in fall snow-cover between 2001 and 2002 is supported by the ANS-data from the period where the accumulated measured snow-depth (mean monthly snow depth) is 63cm 2001 and 23cm during 2002. Unfortunately there are no ANS data from available 2003 (Koheler & Brandt, 2004). In this study we only accounted for the spatial variations of the snow-cover. There are many other factors that affect the snow such as depth, age and the grain size (Gray & Male, 1981). There are no immediate connection between the CO_2-fluxes and the snow cover but as the snow cover limits the shoulder seasons, it affects the CO_2-fluxes.

The area that the CO_2-flux measurements are conducted over is much larger than the DCI window studied here. It also varies with wind direction and wind strength. The DCI window may therefore not always be representative for what the tower are seeing which may contribute to bad correlations. The main fetch area of the tower is the wetter part of the ecosystem (Friborg et al., 2004). The window of investigation is situated in the wet minerotrophic area of the mire. The wet minerotrophic areas do not run out of nutrients and have high rates of carbon exchange. This means that the window of investigation is little affected by drought and limited nutrient levels.

When calculating the CO_2-fluxes with the seasons fixed i.e. what we here call the metrological based seasons (MBS), the spring CO_2-flux becomes a greater source through the course of this study while the summer becomes a greater sink (table 4.3). The fall CO_2-flux is a major source during the fall 2001 but switches into a sink 2002 and 2003. The winter becomes a stronger source from 2001 until 2003. The fall turning into a sink during the fall combined with the stronger source is one of the factors affecting the yearly budget becoming a stronger sink.

When dividing the year into seasons based on the images (IBS) (defined above), the results look somewhat different. Both winter, spring and fall gets shorter from 2001 to 2003 (table 4.4) and the summer gets longer. The IBS-summer is acting as a stronger source from 2001 to 2003. The difference in accumulated CO_2-fluxes for the IBS between 2001 and 2003 is not as big as the difference in the accumulated annual CO_2-flux. Therefore the explanation must be in the mire acting as a source during the rest of the year. The IBS-spring CO_2-fluxes are the strongest source during 2002, compared to half as big 2001 and even smaller 2002. These results are similar to the once found on MBS. Looking at the IBS-fall, the accumulated CO_2-fluxes are especially large in 2001 compared to 2002 and 2003. As the summer during the IBS occupies the source effect the carbon flux during the fall does not switch into a sink. As with the MBS the strong source during the fall in combination with the weak sink during the summer explains the weak yearly sink during 2001. If looking at the accumulated temperature for the IBS, the springs of 2001 and 2002 are much warmer than 2003 (table 4.4). The fall is really warm 2001, much colder 2003 and even negative 2002. This cold temperature is a result from a cold clear fall with little precipitation. This means that according to the IBS, both the spring and fall of 2001 is long and warm. The CO_2-flux release is large during the fall but not during the spring. 2002 has a long and warm spring but a long and cold fall, the CO_2-flux is still low during the fall though. 2003 has the shortest spring and fall, a peculiar cold spring with small amounts of CO_2-fluxes and intermediate fall in terms of temperature and CO_2-fluxes when comparing these years.

As there are only three years with complete information the statistical analysis is limited, therefore only the different types of seasons are compared but not each season separately. This shows a more significant correlation between the temperature and flux in the IBS than in the MBS.

The accumulated temperatures for the study years show that 2001 was coldest and it has been getting warmer over the studied years. As the temperature is getting warmer, the wet part of the mire studied here appears to be taking up more and more carbon.

The accumulated GI-index is not changing much in-between the years corresponding to a limited variation in the incoming radiation (Glob 10), figure 4.5. Since the GI-index is a calculation produced for the current research, there is no other to compare with. The index calculation is performed to make the vegetation comparable in the images since the camera filters-out the IR-wave lengths. The development of the index was not fulfilled as the time limit of the project was approaching. Figure 4.8 shows a significant correlation between the CO_2-flux and the GI-index. To get a more accurate signal, the CO_2-fluxes should be calculated on average between 11AM and 1PM, at the time for the images taken.

In an earlier investigation of CO_2 and CH_4-fluxes on Stordalen by Svensson et al. (1999) dark respiration, the years 1974 to 1995 were compared. The CO_2 emissions were higher 1995 than 1974 even though the weather was warmer and dryer 1974 than 1995. Other studies have shown correlation between the temperature and the dark respiration (Svensson, 1980, Glenn et al., 1993 in Svensson et al. 1999). In this study where we compare the net ecosystem exchange with DCI-information and temperatures in general the correlations are pretty good for the full year, looking at IBS. During campaign measurements in 1995, Friborg et al., (1997) noticed a rise of CO_2-flux as the temperature rose during the spring, probably due to CO_2 locked in the topsoil layer and snow pack. This was not visible during the years of investigation, 2001-2003.

The other comparable sites of similar investigation in NE Greenland (Groendahl et al., submitted) and Northern Finland (Aurela et al., 2004) (their values are recalculated to g CO_2 m-2 yr-1 from C m-2 yr-1) are also sinks but smaller than Stordalen with variations between –6.9 to –91 g CO_2 m-2 yr-1 in Finland and –21.07 to –52.34 g CO_2 m-2 season-1 (season, late winter to early autumn) in Greenland compared to my results ranging from –29.1 to –163.7 g CO_2 m-2. These other studies also find a boost of CO_2 emissions immediate after snowmelt, which is not visible in the fluxdata presented here. Aurela et al., (2004) found the time of snowmelt as the determinant factor for the yearly-accumulated CO_2-fluxes. Aurela et al., (2004) also finds the spring as the governing period for the yearly-accumulated flux as we find the fall as the governing period.

In conclusion the Stordalen mire is acting an increasing sink over the years of investigation. Important to keep in mind is that these results are only concerning vertical CO_2-fluxes. If taking into account other fluxes from the mire such as CH_4, volatile organic compounds (VOCs) and dissolved organic compounds (DOCs) the mire would probably change from a net sink to a net source. As microbial decomposition in anaerobic conditions produces CH_4 and this is common in wetlands there is a high production of CH_4, which is an important greenhouse gas. Even if the mire is a sink concerning carbon it might be a source of greenhouse gases (Friborg et al., 2003). The exchange CH_4 and DOCs are compared to CO_2 is very small, they account for less than 1% (Waddington and Roulet, 2000). The flux is also changing with the variation on the mire, elevated drier areas act as a sink in terms of CO_2 and wet hollow are a major source of CH_4, these differences has not been accounted for in this study. To keep in mind when looking at the total carbon budget of the mire is the fact of lateral fluxes, carbon released from the system by erosion and streams (Billett et al, 2004). Understanding the total carbon balance in a mire is a complex knowledge but by investigating part by part makes a great knowledge of the global carbon budget, a more complex study on the carbon balance on the mire is performed by (Malmer et al., in prep.).

5.1 Future research

To get a better result in the future, my suggestion will be to put the camera at a higher altitude in order to get a better angle and by this be able to monitor larger areas of the mire by DCIs. As the results show in table 4.6, by increasing the elevation of camera to 15m, there will be focus twice as far from the camera as there currently is. If this is to be done the stand for the camera has to be improved to minimize the disorientation of the camera from wind and snow. The first project by Hinkler et al., (2002) is calculating with a greater angle as their camera is situated on an altitude of 500m and is then looking at areas up to 7000m away from the camera. My suggestion is also to remove the IR-filter to the camera to monitor the vegetation changes in a better way. Preferably an entire new camera would be installed with the possibility to save the images as raw-data with no data compression or adjustment for light, when processed the images could be adjusted for incoming light.

A way to develop the research at Stordalen could be to look at snow depth and the physical factors of the snow. Christiansen (2001) made a similar investigation using DCIs, in her research she used measuring sticks all over the study-site in order to determine the snow depths over time at different areas of the valley. If extending the research on snow-cover dynamics on Stordalen this could be a way to monitor the snow depths and snow drift everyday without manual supervision.

6 Conclusions

- The Ortho-software was successful in order to determine snowmelt by using DCIs. When using the Ortho-software, there are limitations on the camera set-up in making accurate interpretations of the images. Nevertheless it has been possible to extract ablation and accumulation curves of the snow and create image based seasons for the studied years.

- The comparison showed no immediate correlation between the changes in snow cover and the CO_2-fluxes. The CO_2-flux was separated into meteorological and image based seasons and compared to the climatic data. The result shows great variation in the accumulated annual CO_2-fluxes. This is depending on the size of the uptake during the summer (sink-span) compared to the source effect during the rest of the year. The accumulated flux during the fall correlated well with the accumulated temperature for the same period.

- The creating of greenness index was successfully performed. The study showed a correlation between GI and the CO_2-fluxes. The result was significant but adjustments are preferable to make the GI comparable from day to day, inter annually and with the carbon fluxes. The recommendation is to get a camera that register infrared light to study vegetation.

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Appendix

Appendix 1

Dataset information on images, snow cover and the GI-index.

Day n	Date	Status	Snow	GI	Date	Status	Snow	GI	Date	Status	Snow	GI
1	1.1.2001		70 %		1.1.2002	missing	55 %		1.1.2003	missing		
2	2.1.2001		72 %		2.1.2002		64 %		2.1.2003	missing		
3	3.1.2001		65 %		3.1.2002		43 %		3.1.2003	missing		
4	4.1.2001		72 %		4.1.2002		17 %		4.1.2003	missing		
5	5.1.2001		63 %		5.1.2002		12 %		5.1.2003	missing		
6	6.1.2001		81 %		6.1.2002		39 %		6.1.2003	missing		
7	7.1.2001		89 %		7.1.2002		42 %		7.1.2003	missing		
8	8.1.2001		82 %		8.1.2002		30 %		8.1.2003	missing		
9	9.1.2001		71 %		9.1.2002				9.1.2003	missing		
10	10.1.2001		70 %		10.1.2002				10.1.2003	missing		
11	11.1.2001		70 %		11.1.2002				11.1.2003	missing		
12	12.1.2001		73 %		12.1.2002		42 %		12.1.2003	missing	78 %	
13	13.1.2001		94 %		13.1.2002		39 %		13.1.2003		82 %	
14	14.1.2001		37 %		14.1.2002		64 %		14.1.2003		88 %	
15	15.1.2001		26 %		15.1.2002				15.1.2003		87 %	
16	16.1.2001		24 %		16.1.2002		81 %		16.1.2003		79 %	
17	17.1.2001		28 %		17.1.2002		78 %		17.1.2003		84 %	
18	18.1.2001		29 %		18.1.2002		75 %		18.1.2003		76 %	
19	19.1.2001		66 %		19.1.2002		56 %		19.1.2003		83 %	
20	20.1.2001		60 %		20.1.2002		53 %		20.1.2003		87 %	
21	21.1.2001		55 %		21.1.2002		47 %		21.1.2003		71 %	
22	22.1.2001		52 %		22.1.2002		52 %		22.1.2003		82 %	
23	23.1.2001		72 %		23.1.2002		61 %		23.1.2003		78 %	
24	24.1.2001		45 %		24.1.2002		72 %		24.1.2003		80 %	
25	25.1.2001		31 %		25.1.2002		64 %		25.1.2003			
26	26.1.2001		41 %		26.1.2002		51 %		26.1.2003		82 %	
27	27.1.2001		26 %		27.1.2002		61 %		27.1.2003		87 %	
28	28.1.2001		28 %		28.1.2002		70 %		28.1.2003		82 %	
29	29.1.2001		45 %		29.1.2002	missing			29.1.2003			
30	30.1.2001		39 %		30.1.2002	missing			30.1.2003			
31	31.1.2001		40 %		31.1.2002	missing			31.1.2003			
32	1.2.2001		45 %		1.2.2002	missing			1.2.2003		45 %	
33	2.2.2001		49 %		2.2.2002	missing			2.2.2003		66 %	
34	3.2.2001		60 %		3.2.2002	missing			3.2.2003		64 %	
35	4.2.2001		44 %		4.2.2002	missing			4.2.2003		62 %	
36	5.2.2001		71 %		5.2.2002	missing			5.2.2003		61 %	
37	6.2.2001		25 %		6.2.2002	missing			6.2.2003		65 %	
38	7.2.2001		65 %		7.2.2002	missing			7.2.2003		32 %	
39	8.2.2001	missing			8.2.2002				8.2.2003		64 %	
40	9.2.2001	missing			9.2.2002				9.2.2003		28 %	
41	10.2.2001	missing			10.2.2002				10.2.2003		43 %	
42	11.2.2001		89 %		11.2.2002				11.2.2003		65 %	

43	12.2.2001 missing		12.2.2002		12.2.2003	70 %
44	13.2.2001	73 %	13.2.2002		13.2.2003	28 %
45	14.2.2001		14.2.2002		14.2.2003	62 %
46	15.2.2001		15.2.2002 missing		15.2.2003	66 %
47	16.2.2001		16.2.2002		16.2.2003	12 %
48	17.2.2001		17.2.2002		17.2.2003	3 %
49	18.2.2001	95 %	18.2.2002		18.2.2003	5 %
50	19.2.2001	90 %	19.2.2002		19.2.2003	
51	20.2.2001	92 %	20.2.2002		20.2.2003	3 %
52	21.2.2001	81 %	21.2.2002		21.2.2003	4 %
53	22.2.2001	96 %	22.2.2002		22.2.2003	4 %
54	23.2.2001	96 %	23.2.2002		23.2.2003	3 %
55	24.2.2001	96 %	24.2.2002		24.2.2003	4 %
56	25.2.2001	83 %	25.2.2002		25.2.2003	6 %
57	26.2.2001	77 %	26.2.2002 missing		26.2.2003	4 %
58	27.2.2001	92 %	27.2.2002 missing		27.2.2003	5 %
59	28.2.2001	92 %	28.2.2002 missing		28.2.2003	7 %
60	1.3.2001	86 %	1.3.2002		1.3.2003	8 %
61	2.3.2001	85 %	2.3.2002 missing		2.3.2003	9 %
62	3.3.2001	78 %	3.3.2002 missing		3.3.2003	9 %
63	4.3.2001	87 %	4.3.2002 missing		4.3.2003	8 %
64	5.3.2001	87 %	5.3.2002 missing		5.3.2003	13 %
65	6.3.2001	91 %	6.3.2002 missing		6.3.2003	8 %
66	7.3.2001	87 %	7.3.2002 missing		7.3.2003	10 %
67	8.3.2001	87 %	8.3.2002 missing	80 %	8.3.2003	13 %
68	9.3.2001	81 %	9.3.2002		9.3.2003	8 %
69	10.3.2001	83 %	10.3.2002		10.3.2003	7 %
70	11.3.2001	84 %	11.3.2002		11.3.2003	16 %
71	12.3.2001	86 %	12.3.2002	88 %	12.3.2003	
72	13.3.2001	89 %	13.3.2002	75 %	13.3.2003	8 %
73	14.3.2001	90 %	14.3.2002	73 %	14.3.2003	
74	15.3.2001	66 %	15.3.2002	95 %	15.3.2003	
75	16.3.2001	95 %	16.3.2002	71 %	16.3.2003	91 %
76	17.3.2001	86 %	17.3.2002	66 %	17.3.2003	69 %
77	18.3.2001	80 %	18.3.2002	75 %	18.3.2003	
78	19.3.2001	89 %	19.3.2002	89 %	19.3.2003	78 %
79	20.3.2001	87 %	20.3.2002	63 %	20.3.2003	79 %
80	21.3.2001	89 %	21.3.2002	85 %	21.3.2003	76 %
81	22.3.2001	72 %	22.3.2002	84 %	22.3.2003	
82	23.3.2001	86 %	23.3.2002	84 %	23.3.2003	6 %
83	24.3.2001	88 %	24.3.2002	84 %	24.3.2003	19 %
84	25.3.2001	87 %	25.3.2002	86 %	25.3.2003	46 %
85	26.3.2001	86 %	26.3.2002	85 %	26.3.2003	14 %
86	27.3.2001	85 %	27.3.2002	82 %	27.3.2003	
87	28.3.2001	80 %	28.3.2002	72 %	28.3.2003	73 %
88	29.3.2001	84 %	29.3.2002	85 %	29.3.2003	80 %
89	30.3.2001	91 %	30.3.2002	74 %	30.3.2003	80 %
90	31.3.2001	86 %	31.3.2002	84 %	31.3.2003	80 %
91	1.4.2001	75 %	1.4.2002	85 %	1.4.2003	
92	2.4.2001	77 %	2.4.2002	85 %	2.4.2003	64 %

93	3.4.2001	72 %		3.4.2002	77 %		3.4.2003	46 %	
94	4.4.2001			4.4.2002	76 %		4.4.2003	78 %	
95	5.4.2001	77 %		5.4.2002	72 %		5.4.2003		
96	6.4.2001	72 %		6.4.2002	66 %		6.4.2003	40 %	
97	7.4.2001	75 %		7.4.2002	80 %		7.4.2003	83 %	
98	8.4.2001	89 %		8.4.2002			8.4.2003	78 %	
99	9.4.2001	83 %		9.4.2002			9.4.2003	78 %	
100	10.4.2001	80 %		10.4.2002			10.4.2003	53 %	
101	11.4.2001			11.4.2002			11.4.2003	64 %	
102	12.4.2001			12.4.2002	63 %		12.4.2003	42 %	
103	13.4.2001	89 %		13.4.2002	76 %		13.4.2003	24 %	
104	14.4.2001	87 %		14.4.2002	83 %		14.4.2003	19 %	
105	15.4.2001	86 %		15.4.2002	92 %		15.4.2003	15 %	
106	16.4.2001	53 %		16.4.2002	71 %		16.4.2003	11 %	
107	17.4.2001	88 %		17.4.2002	66 %		17.4.2003	8 %	
108	18.4.2001	88 %		18.4.2002	84 %		18.4.2003	12 %	
109	19.4.2001	87 %		19.4.2002	66 %		19.4.2003	3 %	
110	20.4.2001	83 %		20.4.2002	82 %		20.4.2003	3 %	
111	21.4.2001	80 %		21.4.2002	27 %		21.4.2003		41.7
112	22.4.2001	84 %		22.4.2002	28 %		22.4.2003		47.4
113	23.4.2001	69 %		23.4.2002	27 %		23.4.2003		45.3
114	24.4.2001	50 %		24.4.2002	23 %		24.4.2003		41.3
115	25.4.2001	19 %		25.4.2002	21 %	43.4	25.4.2003		45.3
116	26.4.2001	10 %		26.4.2002		35.1	26.4.2003		57.3
117	27.4.2001	5 %		27.4.2002		4.25	27.4.2003		36
118	28.4.2001	5 %		28.4.2002		51.4	28.4.2003		36.8
119	29.4.2001		26.4	29.4.2002		26	29.4.2003		47.6
120	30.4.2001		19.8	30.4.2002		35.9	30.4.2003		45.7
121	1.5.2001		38.8	1.5.2002		11.2	1.5.2003		50.2
122	2.5.2001		41.5	2.5.2002		45.5	2.5.2003		48
123	3.5.2001		23.8	3.5.2002		20.6	3.5.2003		41.4
124	4.5.2001		23.6	4.5.2002		49.8	4.5.2003		38.9
125	5.5.2001		40.7	5.5.2002		48.7	5.5.2003		46.1
126	6.5.2001		36.7	6.5.2002		0	6.5.2003		31.1
127	7.5.2001		12.5	7.5.2002		0	7.5.2003		26.8
128	8.5.2001		35	8.5.2002		0	8.5.2003		0
129	9.5.2001		44	9.5.2002		0	9.5.2003		51
130	10.5.2001		28.8	10.5.2002		0	10.5.2003		53
131	11.5.2001		36.6	11.5.2002		0	11.5.2003		52.4
132	12.5.2001		21.9	12.5.2002			12.5.2003		30.2
133	13.5.2001		35.2	13.5.2002		27.2	13.5.2003		24.7
134	14.5.2001		23.6	14.5.2002		48.3	14.5.2003		37.9
135	15.5.2001		26.6	15.5.2002		42	15.5.2003		37
136	16.5.2001		41.2	16.5.2002		37.8	16.5.2003		63.4
137	17.5.2001		8.95	17.5.2002		49.6	17.5.2003		32.6
138	18.5.2001		24.1	18.5.2002		33.3	18.5.2003		55.1
139	19.5.2001		40.4	19.5.2002		46.9	19.5.2003		47.7
140	20.5.2001		17.7	20.5.2002		42	20.5.2003		24.3
141	21.5.2001		31.7	21.5.2002		56.8	21.5.2003		50.9
142	22.5.2001		30.1	22.5.2002		45.4	22.5.2003		24.8

143	23.5.2001	50	23.5.2002	25.3	23.5.2003		68.7
144	24.5.2001	50.7	24.5.2002	34.3	24.5.2003		46.9
145	25.5.2001	21.4	25.5.2002	28.4	25.5.2003		43.8
146	26.5.2001	39.8	26.5.2002	73.4	26.5.2003		-0.4
147	27.5.2001	26.9	27.5.2002	17.4	27.5.2003		46.1
148	28.5.2001	39.7	28.5.2002	18	28.5.2003		26.6
149	29.5.2001	31.7	29.5.2002	28.6	29.5.2003		49.9
150	30.5.2001	55.5	30.5.2002	36.2	30.5.2003		56.6
151	31.5.2001	30.6	31.5.2002	42.4	31.5.2003		36
152	1.6.2001	26	1.6.2002	50.3	1.6.2003		0
153	2.6.2001	48.7	2.6.2002	59.3	2.6.2003		60.5
154	3.6.2001	43	3.6.2002	52.4	3.6.2003		44.6
155	4.6.2001	49.8	4.6.2002		4.6.2003		35.6
156	5.6.2001	47.7	5.6.2002 missing	63	5.6.2003		46.2
157	6.6.2001	39.3	6.6.2002	43.4	6.6.2003		57.2
158	7.6.2001	32.5	7.6.2002		7.6.2003		57.6
159	8.6.2001	17.9	8.6.2002		8.6.2003		63
160	9.6.2001	42.6	9.6.2002	62	9.6.2003		51.5
161	10.6.2001	31.3	10.6.2002		10.6.2003		68.6
162	11.6.2001	38.9	11.6.2002		11.6.2003		69.1
163	12.6.2001	47.3	12.6.2002	80	12.6.2003		70.1
164	13.6.2001	40.5	13.6.2002	94.7	13.6.2003		59.2
165	14.6.2001	54.8	14.6.2002	90.6	14.6.2003		57.6
166	15.6.2001	47.5	15.6.2002	79.4	15.6.2003		0
167	16.6.2001	37	16.6.2002	70.4	16.6.2003		62.5
168	17.6.2001	48.3	17.6.2002	81.5	17.6.2003	missing	63.3
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170	19.6.2001	54	19.6.2002	71.9	19.6.2003		82.8
171	20.6.2001	44	20.6.2002	68.4	20.6.2003		58.8
172	21.6.2001	59.5	21.6.2002	41.3	21.6.2003		72.1
173	22.6.2001	74.2	22.6.2002	59.9	22.6.2003		67
174	23.6.2001	50.3	23.6.2002	63.8	23.6.2003		69.6
175	24.6.2001	57.6	24.6.2002	91.1	24.6.2003		38.5
176	25.6.2001	59.4	25.6.2002	71.2	25.6.2003		64.2
177	26.6.2001	70	26.6.2002	76.8	26.6.2003		70.4
178	27.6.2001	56.8	27.6.2002	47	27.6.2003		70
179	28.6.2001	71.7	28.6.2002	55.7	28.6.2003		54.8
180	29.6.2001	51.5	29.6.2002	83.4	29.6.2003		50.3
181	30.6.2001	35.8	30.6.2002	70.5	30.6.2003		63.3
182	1.7.2001	65.4	1.7.2002	80.1	1.7.2003		62.4
183	2.7.2001	59.4	2.7.2002	86.7	2.7.2003		67
184	3.7.2001	63.5	3.7.2002	61	3.7.2003		58.1
185	4.7.2001	35.8	4.7.2002	56.5	4.7.2003		71.8
186	5.7.2001	57.4	5.7.2002	51.9	5.7.2003		72.9
187	6.7.2001	55.1	6.7.2002	58.1	6.7.2003		53.2
188	7.7.2001	50.3	7.7.2002	89.6	7.7.2003		96.5
189	8.7.2001	61.1	8.7.2002	62.6	8.7.2003		68.2
190	9.7.2001	63.8	9.7.2002		9.7.2003		60.2
191	10.7.2001	63.9	10.7.2002		10.7.2003		85.3
192	11.7.2001	72.1	11.7.2002		11.7.2003		61.3

193	12.7.2001	45.3	12.7.2002	69	12.7.2003	72.1
194	13.7.2001	61.6	13.7.2002	59.3	13.7.2003	66.6
195	14.7.2001	62.8	14.7.2002	64.3	14.7.2003	63.4
196	15.7.2001	68.3	15.7.2002	74.1	15.7.2003	77.3
197	16.7.2001	57.3	16.7.2002	64.3	16.7.2003	82.8
198	17.7.2001	77.4	17.7.2002	79.5	17.7.2003	82
199	18.7.2001	55.2	18.7.2002	88	18.7.2003	77.5
200	19.7.2001	45.3	19.7.2002	71.2	19.7.2003	64.3
201	20.7.2001	75.6	20.7.2002	71.8	20.7.2003	51.2
202	21.7.2001	50.3	21.7.2002	54.9	21.7.2003	61.8
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204	23.7.2001	75.9	23.7.2002	74.9	23.7.2003	64
205	24.7.2001	57.1	24.7.2002	72.6	24.7.2003	66.8
206	25.7.2001	44.8	25.7.2002	66.8	25.7.2003	81.3
207	26.7.2001	49.9	26.7.2002	42.9	26.7.2003	78.8
208	27.7.2001	54.9	27.7.2002		27.7.2003	81.5
209	28.7.2001	77.1	28.7.2002 missing		28.7.2003	62.8
210	29.7.2001	71.2	29.7.2002 missing	36.9	29.7.2003	74.6
211	30.7.2001	76.4	30.7.2002	67.7	30.7.2003	76.2
212	31.7.2001		31.7.2002	68.4	31.7.2003	72
213	1.8.2001		1.8.2002	58.5	1.8.2003	91.2
214	2.8.2001	48.9	2.8.2002	57.4	2.8.2003	87.8
215	3.8.2001	63.5	3.8.2002	56.4	3.8.2003	76.7
216	4.8.2001	45.3	4.8.2002	58.5	4.8.2003	89
217	5.8.2001	52.6	5.8.2002	0	5.8.2003	44.7
218	6.8.2001	65.9	6.8.2002	0	6.8.2003	70
219	7.8.2001	51.2	7.8.2002	62.6	7.8.2003	69.6
220	8.8.2001	57.6	8.8.2002	63.3	8.8.2003	79.9
221	9.8.2001	32.5	9.8.2002	61.7	9.8.2003	34.3
222	10.8.2001	78.4	10.8.2002	67.6	10.8.2003	68.9
223	11.8.2001	72.6	11.8.2002	57.6	11.8.2003	66.9
224	12.8.2001	48.8	12.8.2002	63.3	12.8.2003	0
225	13.8.2001	53.6	13.8.2002	58	13.8.2003	64.2
226	14.8.2001	74.3	14.8.2002	54.7	14.8.2003	61.8
227	15.8.2001	79.5	15.8.2002	59.9	15.8.2003	81.2
228	16.8.2001		16.8.2002	68.9	16.8.2003	73
229	17.8.2001	63	17.8.2002	75.7	17.8.2003	63.8
230	18.8.2001	53.9	18.8.2002	50.2	18.8.2003	66.1
231	19.8.2001	45.6	19.8.2002	53.4	19.8.2003	74.1
232	20.8.2001	58.9	20.8.2002	68	20.8.2003	63.9
233	21.8.2001	54.8	21.8.2002	69.7	21.8.2003	48.7
234	22.8.2001	70.8	22.8.2002	36.7	22.8.2003	84.1
235	23.8.2001	19.9	23.8.2002	67.6	23.8.2003	51
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237	25.8.2001	46.8	25.8.2002	70.8	25.8.2003	44.9
238	26.8.2001	70.6	26.8.2002	47.2	26.8.2003	54.5
239	27.8.2001	47.4	27.8.2002	53.1	27.8.2003	44.2
240	28.8.2001	24.2	28.8.2002	49.1	28.8.2003	45.7
241	29.8.2001	42.6	29.8.2002	66.3	29.8.2003	56.5
242	30.8.2001	41.6	30.8.2002	50	30.8.2003	49.7

243	31.8.2001		49.7	31.8.2002		65.4	31.8.2003		79
244	1.9.2001		33	1.9.2002		42.7	1.9.2003		58.5
245	2.9.2001		46.5	2.9.2002		41.2	2.9.2003		76.9
246	3.9.2001		39.4	3.9.2002		15.2	3.9.2003		42.8
247	4.9.2001		32.9	4.9.2002		34.6	4.9.2003		45.1
248	5.9.2001		48.3	5.9.2002			5.9.2003		41.4
249	6.9.2001		45.7	6.9.2002			6.9.2003		68.8
250	7.9.2001		40.1	7.9.2002	missing	44	7.9.2003		67.6
251	8.9.2001		7.45	8.9.2002		53.1	8.9.2003		63.4
252	9.9.2001		46	9.9.2002		42.9	9.9.2003		54.2
253	10.9.2001		13.4	10.9.2002		55.8	10.9.2003		61.5
254	11.9.2001		27	11.9.2002		58.1	11.9.2003		48.3
255	12.9.2001		36.7	12.9.2002		44	12.9.2003		49.8
256	13.9.2001		78.3	13.9.2002		46.4	13.9.2003		57.5
257	14.9.2001		28	14.9.2002		42.5	14.9.2003		37.1
258	15.9.2001		47.1	15.9.2002		48.1	15.9.2003		43.2
259	16.9.2001		24.6	16.9.2002		22.6	16.9.2003		37.1
260	17.9.2001		22.7	17.9.2002		44.7	17.9.2003		43.2
261	18.9.2001		54.3	18.9.2002		26.2	18.9.2003		23.8
262	19.9.2001		47.2	19.9.2002		30	19.9.2003		43.3
263	20.9.2001		48.3	20.9.2002		50	20.9.2003		0
264	21.9.2001		32.6	21.9.2002		44.4	21.9.2003		31.7
265	22.9.2001		27.7	22.9.2002		43	22.9.2003		32.2
266	23.9.2001		39	23.9.2002		40.5	23.9.2003		34.9
267	24.9.2001		37.6	24.9.2002		17	24.9.2003		51
268	25.9.2001		22.1	25.9.2002		13	25.9.2003		59.9
269	26.9.2001			26.9.2002		48.8	26.9.2003		45.3
270	27.9.2001		39.3	27.9.2002		42.5	27.9.2003		28.9
271	28.9.2001		19.4	28.9.2002		27.2	28.9.2003		33.4
272	29.9.2001		20.8	29.9.2002		9.6	29.9.2003		47.7
273	30.9.2001		37.9	30.9.2002		-11	30.9.2003		48.9
274	1.10.2001		39.9	1.10.2002		0	1.10.2003		54.9
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277	4.10.2001	13 %		4.10.2002		31.4	4.10.2003		46.9
278	5.10.2001	1 %		5.10.2002		0	5.10.2003		31.4
279	6.10.2001		62.7	6.10.2002		0	6.10.2003		60.3
280	7.10.2001		9.5	7.10.2002		-19	7.10.2003		59.5
281	8.10.2001		20.8	8.10.2002		17.4	8.10.2003		30.4
282	9.10.2001		8	9.10.2002		21.1	9.10.2003		26.2
283	10.10.2001		43.2	10.10.2002		29	10.10.2003		56.7
284	11.10.2001		27.1	11.10.2002		-1.8	11.10.2003		36.3
285	12.10.2001		40.1	12.10.2002		44.4	12.10.2003		47.5
286	13.10.2001		24.3	13.10.2002		44.4	13.10.2003		56.3
287	14.10.2001		35.5	14.10.2002		76.8	14.10.2003		13.2
288	15.10.2001		24.7	15.10.2002		45.4	15.10.2003		37.8
289	16.10.2001		25.8	16.10.2002	4 %		16.10.2003		31.4
290	17.10.2001		13.9	17.10.2002	5 %		17.10.2003		22
291	18.10.2001		21.6	18.10.2002	14 %		18.10.2003	4 %	
292	19.10.2001		40.4	19.10.2002	14 %		19.10.2003	3 %	

293	20.10.2001	1 %	20.10.2002	13 %	20.10.2003	1 %
294	21.10.2001	5 %	21.10.2002	8 %	21.10.2003	1 %
295	22.10.2001	7 %	22.10.2002	5 %	22.10.2003	4 %
296	23.10.2001	12 %	23.10.2002	12 %	23.10.2003	1 %
297	24.10.2001	25 %	24.10.2002	6 %	24.10.2003	1 %
298	25.10.2001	13 %	25.10.2002	5 %	25.10.2003	3 %
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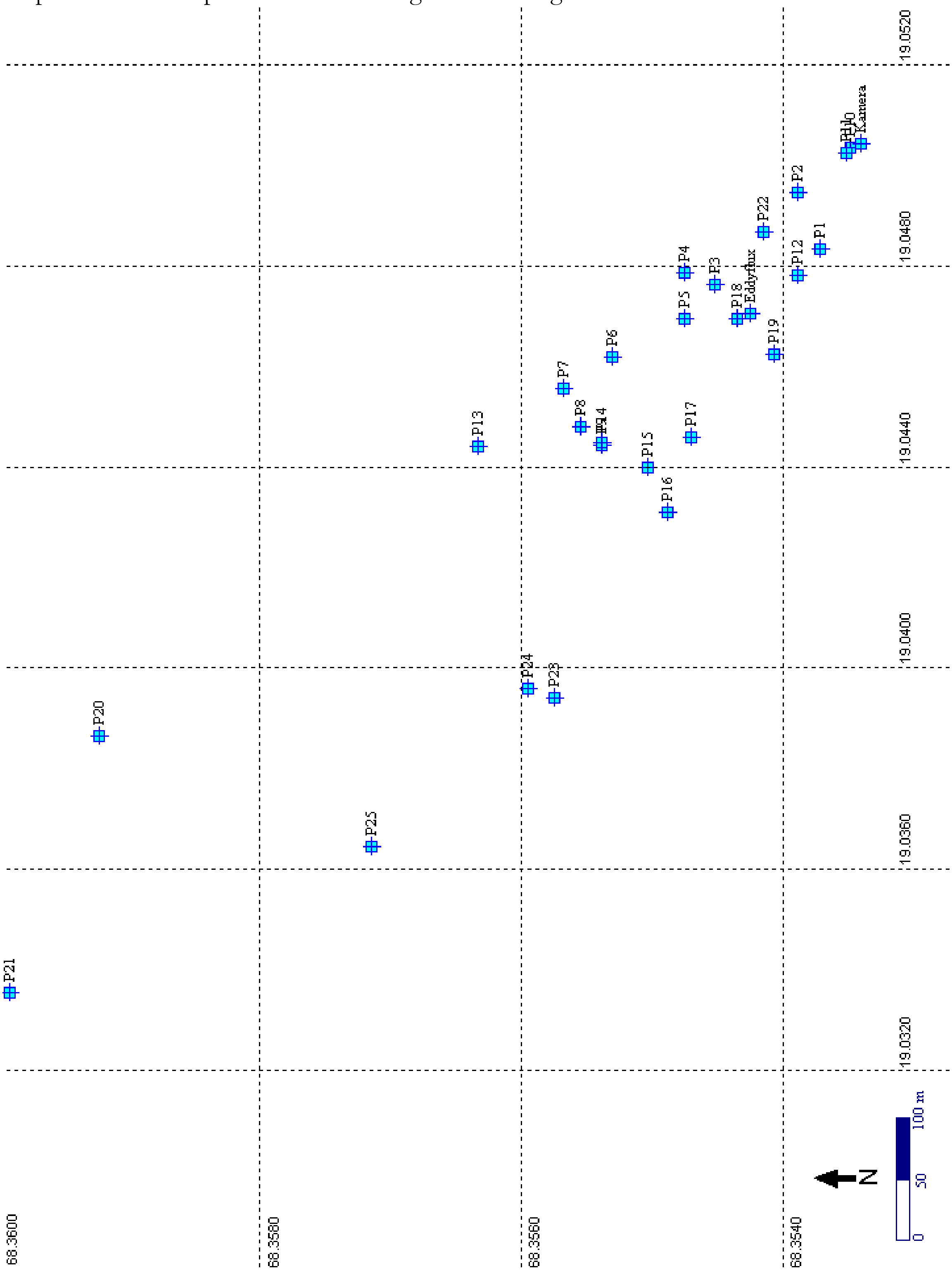
300	27.10.2001	5 %	27.10.2002	5 %	27.10.2003	2 %
301	28.10.2001	4 %	28.10.2002	6 %	28.10.2003	2 %
302	29.10.2001	5 %	29.10.2002	5 %	29.10.2003	6 %
303	30.10.2001	18 %	30.10.2002	3 %	30.10.2003	3 %
304	31.10.2001	14 %	31.10.2002	46 %	31.10.2003	2 %
305	1.11.2001	13 %	1.11.2002		1.11.2003	5 %
306	2.11.2001	17 %	2.11.2002		2.11.2003	1 %
307	3.11.2001	13 %	3.11.2002	46 %	3.11.2003	1 %
308	4.11.2001	17 %	4.11.2002	3 %	4.11.2003	
309	5.11.2001	12 %	5.11.2002		5.11.2003	
310	6.11.2001	21 %	6.11.2002		6.11.2003	
311	7.11.2001	78 %	7.11.2002	6 %	7.11.2003	
312	8.11.2001	69 %	8.11.2002	38 %	8.11.2003	
313	9.11.2001	78 %	9.11.2002	7 %	9.11.2003	
314	10.11.2001	84 %	10.11.2002	7 %	10.11.2003	
315	11.11.2001	74 %	11.11.2002	6 %	11.11.2003	
316	12.11.2001	85 %	12.11.2002	6 %	12.11.2003	
317	13.11.2001	74 %	13.11.2002	7 %	13.11.2003	
318	14.11.2001	80 %	14.11.2002	8 %	14.11.2003	
319	15.11.2001	75 %	15.11.2002	8 %	15.11.2003	2 %
320	16.11.2001	87 %	16.11.2002	7 %	16.11.2003	1 %
321	17.11.2001	63 %	17.11.2002	5 %	17.11.2003	2 %
322	18.11.2001	91 %	18.11.2002	8 %	18.11.2003	2 %
323	19.11.2001		19.11.2002	13 %	19.11.2003	2 %
324	20.11.2001	83 %	20.11.2002	32 %	20.11.2003	3 %
325	21.11.2001	83 %	21.11.2002	4 %	21.11.2003	4 %
326	22.11.2001	82 %	22.11.2002	13 %	22.11.2003	11 %
327	23.11.2001	76 %	23.11.2002	13 %	23.11.2003	10 %
328	24.11.2001	83 %	24.11.2002	21 %	24.11.2003	47 %
329	25.11.2001	83 %	25.11.2002	28 %	25.11.2003	38 %
330	26.11.2001	79 %	26.11.2002	21 %	26.11.2003	3 %
331	27.11.2001	86 %	27.11.2002	11 %	27.11.2003	2 %
332	28.11.2001	85 %	28.11.2002	13 %	28.11.2003	3 %
333	29.11.2001	87 %	29.11.2002		29.11.2003	2 %
334	30.11.2001	85 %	30.11.2002 missing		30.11.2003	3 %
335	1.12.2001	89 %	1.12.2002 missing		1.12.2003	2 %
336	2.12.2001	92 %	2.12.2002 missing		2.12.2003	2 %
337	3.12.2001	87 %	3.12.2002 missing		3.12.2003	20 %
338	4.12.2001	84 %	4.12.2002 missing		4.12.2003	3 %
339	5.12.2001	75 %	5.12.2002 missing		5.12.2003	68 %
340	6.12.2001	76 %	6.12.2002 missing		6.12.2003	65 %
341	7.12.2001	76 %	7.12.2002 missing		7.12.2003	
342	8.12.2001	82 %	8.12.2002 missing		8.12.2003	

343	9.12.2001	86 %	9.12.2002	missing		9.12.2003		
344	10.12.2001	87 %	10.12.2002	missing		10.12.2003		80 %
345	11.12.2001	50 %	11.12.2002	missing		11.12.2003		74 %
346	12.12.2001	50 %	12.12.2002	missing	10 %	12.12.2003		
347	13.12.2001	50 %	13.12.2002		9 %	13.12.2003		
348	14.12.2001	53 %	14.12.2002		8 %	14.12.2003		69 %
349	15.12.2001	38 %	15.12.2002		10 %	15.12.2003		87 %
350	16.12.2001		16.12.2002		9 %	16.12.2003		90 %
351	17.12.2001		17.12.2002		8 %	17.12.2003		84 %
352	18.12.2001	62 %	18.12.2002		29 %	18.12.2003	missing	81 %
353	19.12.2001	76 %	19.12.2002		79 %	19.12.2003		89 %
354	20.12.2001	80 %	20.12.2002		78 %	20.12.2003		87 %
355	21.12.2001	80 %	21.12.2002		78 %	21.12.2003		90 %
356	22.12.2001	82 %	22.12.2002		82 %	22.12.2003		82 %
357	23.12.2001	83 %	23.12.2002			23.12.2003		
358	24.12.2001	75 %	24.12.2002	missing		24.12.2003		
359	25.12.2001	85 %	25.12.2002	missing		25.12.2003		67 %
360	26.12.2001	71 %	26.12.2002	missing		26.12.2003		80 %
361	27.12.2001	50 %	27.12.2002	missing		27.12.2003		79 %
362	28.12.2001	61 %	28.12.2002	missing		28.12.2003		86 %
363	29.12.2001	66 %	29.12.2002	missing		29.12.2003		83 %
364	30.12.2001	58 %	30.12.2002	missing		30.12.2003		77 %
365	31.12.2001	49 %	31.12.2002	missing		31.12.2003		67 %

Appendix 2

Map of the control point coordinates registered during field-work 2004-08-24.



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