Satellite Monitoring of the Biomass Production in Southern Greenland

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Based on satellite data from Southern Greenland the application of Normalized Difference Vegetation Index (NDVI) for monitoring biomass production has been evaluated. Field measurements of spectral reflectance data are quantitatively correlated with clipped samples of total above-ground biomass production. The relation between NDVI measured on the ground and biomass production is discussed. The seasonal and geographical variation in NDVI is correlated with the climate and water balance. The potential production is estimated as the product of mean NDVI and the length of the growing season. The results suggest that operational satellite monitoring of NDVI provides valuable assistance in agricultural management and forward planning of the potential breeding capacity in an arctic/subarctic environment.

Keywords: *Southern Greenland, Normalized Difference Vegetation Index, Biomass production, NOAA-AVHRR.*

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From 1984 to 1987 the Ministry for Greenland has sponsored a research project on natural resources and primary productivity in relation to sheep-breeding in the southern part of Greenland. During the years the remote sensing technique of monitoring the biomass production from satellite data has been greatly elaborated. Total above-ground biomass production has been monitored for the Sahel region (Tucker et al., 1985), and intensive measurements in a sheep-breeding area in New Zealand have shown a significant correlation between actual pasture production and satellite-derived estimates (Taylor et al., 1985).

The aim of the project was to evaluate application of satellite data for monitoring the potential biomass production in an arctic/subarctic environment.

SATELLITE DATA APPROACH

Vegetation classification with early Landsat MSS data has previously been utilized by Folving (1986), who found that the principal component analysis gives accurate results in the classification of different vegetation types.

Due to the high latitude of the study area Meteosat data cannot be applied, and the recent Spot and Landsat TM data are only covering parts of the area in the autumn. Because of the close position to the major Atlantic cyclone track Southern Greenland experiences long periods of dense cloud cover, which favors the choice of NOAA-AVHRR data (Advanced Very High Resolution Radiometer). The NOAA satellite system has been described and its use in agricultural monitoring comprehensively reviewed by Yates et al. (1984). Tucker et al. (1983) used these data for monitoring vegetation in the Sahel area, and Justice et al. (1985) extended the use to study the phenology of continental-sized areas.

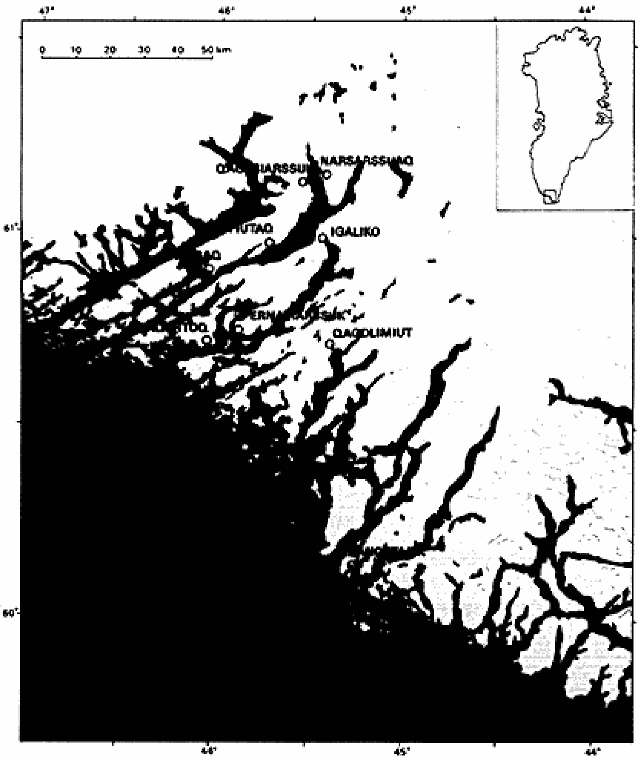

Fig. 1. Map of the area.

Channels 1 and 2 on the NOAA-AVHRR measure reflected solar radiation, while channels 3-5 are designed for infrared and thermal infrared radiation (table 1). The first spectral channel lies in that part of the spectrum where the chlorophyll in the plants causes considerable absorption of incoming radiation, while the second channel lies where the leaf area and leaf structure lead to considerable reflectance. A green vegetated surface will thus give a high signal in channel 2 and a relatively low in channel 1; the

Channel no.	Bandwidth µm	Denomination
1	0.56 - 0.68	Visible
2	0.725 - 1.10	Near infrared
3	3.55 - 3.93	Mid infrared
4	10.3 - 11.3	Thermal infrared
5	11.5 - 12.5	Thermal infrared

Table 1. Bandwidth for the channels on NOAA-AVHRR.

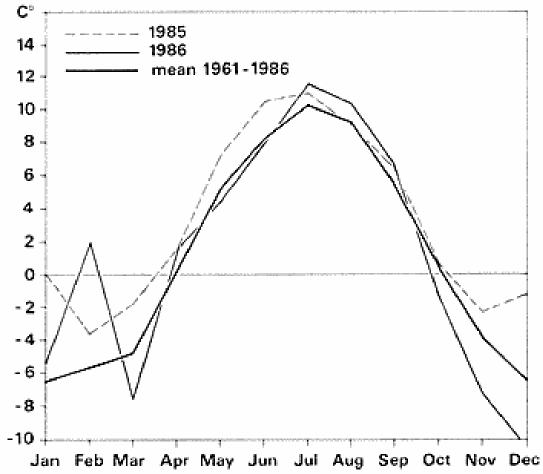

Fig. 2. Monthly mean temperature at Narssarssuaq in 1985, 1986 and the period 1961-1986.

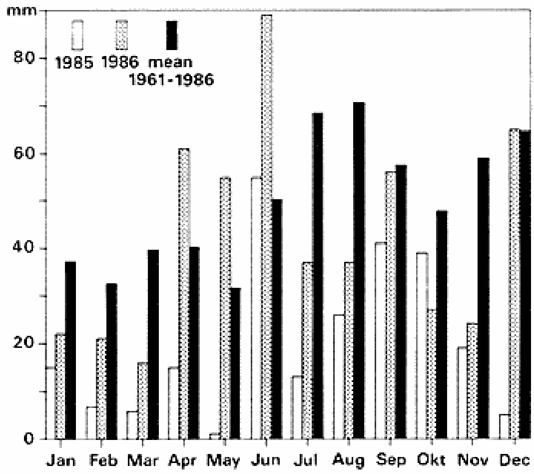

Fig. 3. Monthly mean precipitation at Narssarssuaq in 1985, 1986 and the period 1961-1986.

difference between the radiation flux in channel 2 (RCh2) and channel 1(RCh1) shows a high correlation with vegetation parameters such as biomass and green-leaf area. The contrast between the response from the two channels can be conveniently shown by a ratio transform, and one of the most used transforms for agricultural purposes during the last years, is the Normalized Difference Vegetation Index (NDVI), which is defined as:

$$NDVI = (RCH2-RCh1) / (RCh2+RCh1)$$

The ratio of the bands is of considerable use to reduce variations due to surface topography and to compensate for variations in radiance as a function of sun elevation for different parts of the scenes (Holben, 1987), which is especially valuable for studies in arctic/subarctic areas with a large-scaled topography. However, it should be noted that using the ratio does not eliminate additive effects due to atmospheric attenuation.

THE STUDY AREA

The landscape (fig. 1) is characterized by a coastal region of the skerries type and deep fjords nearly reaching the alpine border area of the Ice Cap. The sheep-breeding is located in the subalpine central region between Upernaviarsuk, Qagssiarsuk and Qagdlimiut.

Climatologically, major parts of the area belong to the arctic/subarctic marginal zone, defined by the presence of the 10 °C-isotherm for the warmest month. Due to the maritime influence the mean July temperature at sea level decreases southwestward from around 9-12 °C in Narsarssuaq to 5-9 °C in Qaqortoq. The mean annual temperature in Narssarssuaq is 1.0 °C with a yearly variation of 22 °C (fig. 2). The mean annual precipitation is highest in the coastal area with 820 mm at Qaqortoq and decreases to 600 mm in Narssarssuaq. Approximately 50 % of the precipitation fall in the growing season (May-September) (fig. 3). In very dry years only 110 mm of precipitation fall in the inner parts of the region during the growing season against 170 mm in the coastal areas. The daily evapotranspiration is 1-3 mm and the annual evapotranspiration increases from 150 mm in the coastal areas to 300 mm in the inner parts of the area.

The climate is characterized by frequent occurrences of a strong, dry, foehn wind from the Ice Cap. In a grass production context it is notable that the foehn often results in a potential evapotranspiration of up to 16 mm-/day. As foehn situations may occur 6-7 times during the growing season (fig. 5), this will in years with low precipitation lead to a stress on the vegetation, which means lower dry-matter production.

For the production, other physical parameters are important as well. This holds especially for the soil development in relation to soil water capacity. The field capacity in the central region's lowland varies from 50 mm to 150 mm. During the summer dry periods may cause drought on S-SE facing valley sides due to the lack of sufficient soil water magazines in the small, loose and coarse-grained deposits.

The vegetation is extremely well adapted to the climatic and topographical conditions within the region. Fell-field vegetation is met with on top of the wind-swept ridges, stony barrens and stony terraces. Grassland is widespread on slopes well protected by a not too long persisting snow cover during the winter. Wetland types as fen and marsh are found as narrow zones along lakes and streams, while in the subarctic inner region shrub of birch and willow reaching heights of 2-3 m can be found in protected valleys (Feilberg, 1984). From the coastal areas the luxuriance of the vegetation increases inland, but larger homogeneous areas with vetegation are rarely found, whereas patchy heterogeneuos plant communities between bare

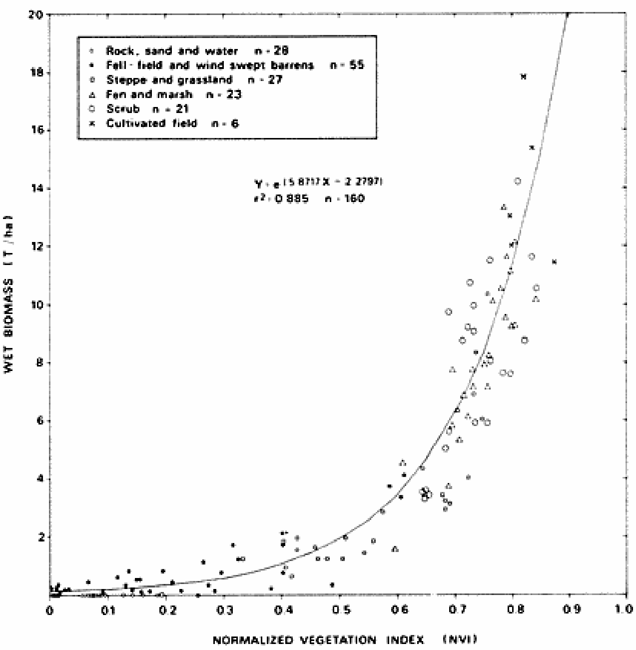

Fig. 4. The relationship between wet biomass and NDVI based on 160 samples collected during the optimum of the growing season in 1987.

rocks are common.

THE FIELD WORK CAMPAIGNS

Each year since 1985 field campaigns have been conducted in the growing season to collect ground reference data on radiation- and energybalance parameters.

In 1987, these were supplemented by radiometric and biomass production measurements. The surface values in NDVI were estimated by applying 2 hand-held Milton radiometers, one directed toward the target and the other toward the reference panel (Kodak grey card, 152-7795). The measurements were taken simultaneously in order to eliminate errors due to change in irradiance. Samples were collected from 160 plots at 30 sites. At each site three pair of measurements were taken in the wavelength spectrum corresponding to NOAA-AVHRR (Table 1).

At 111 plots a 25.5 cm^2 area was clipped and at 21 plots with scrub a 1 m^2 area was clipped. Each sampling was dried at 115 °C and subsequently weighed to estimate dry biomass/m^2. Before clipping the distribution of species and the percentage cover were estimated from a small 10x10 point grid.

In fig. 4 is shown the relationship between ground-measured NDVI and total accumulated wet-matter in the middle of the growing season. More than 80 % of total variation can be explained by the hyperbolic curve. It is striking that the function is very similar to the functions from the marginal zones of Sahel, derived by Tucker (1985), but the estimates from Greenland are approx. 50 % lower than estimates from Sahel, which might be due to differences in chlorophyll contents and leaf area for the plant communities in the two areas. Another source of variation is the soil brightness influence (Huete & Jackson, 1987), which causes NDVI-values over incomplete canopies to change as a result of the reflectance factor of the underlying soil. Lighter colored soils produce lower NDVI-values, and similar brightness effects can be seen with gray (dark) and yellow (light) litter on the ground. Brightness effects are most pronounced over the intermediate canopy covers and decreases in intensity at both very low and nearly full canopy covers.

PROCESSING OF SATELLITE DATA AND ATMOSPHERIC CORRECTIONS

The satellite data was selected from data archives at the receiving station in Dundee, Scotland, and the image processing carried out by a system developed at Geographical Institute, University of Copenhagen (Rasmussen et al., 1987).

The geometrical calibration was performed in three steps:

1. a systematic correction for the panoramic effects;
2. a transformation to UTM-model by cross-correlation technique allowing a high ub-pixel accuracy;
3. the two transformations from the previous steps are mathematically combined into a single transformation, so that only one resampling is necessary.

In total, 45 NOAA-AVHHR growing season subscenes have been selected from 1985, 1986 and 1987. As the only criterion has been least possible cloud cover, the scan angles vary from 0° to 48° off-nadir.

Due to the great variation in scan angle, and the scattering and absorption of the solar radiation in the atmosphere, the NDVI-value can be expected to decline with increasing off-nadir scan angle. The backscatter direction is influenced more than the forward scattering, and a relationship formulated by Holben et al. (1986) has been applied.

The amount of NDVI-reduction depends also on the atmospheric water vapor content, which can be derived by the "split-window" technique as used in thermal infrared radiometry. The attenuation through the atmosphere due to water vapor is greater on the thermal radiation sensed by NOAA-AVHRR channel 5 than on channel 4, and the difference between the brightness temperatures (T4-T5) can be taken as a measure of the optical depht of the atmosphere's water vapor and can be used for a correction of the NDVI-value (Hansen & Søgaard, 1987). The results of the atmospheric correction can be seen in figures 5 and 6.

Southern Greenland is a very cloudy area and completely cloudfree scenes are very rare. The "split-window"

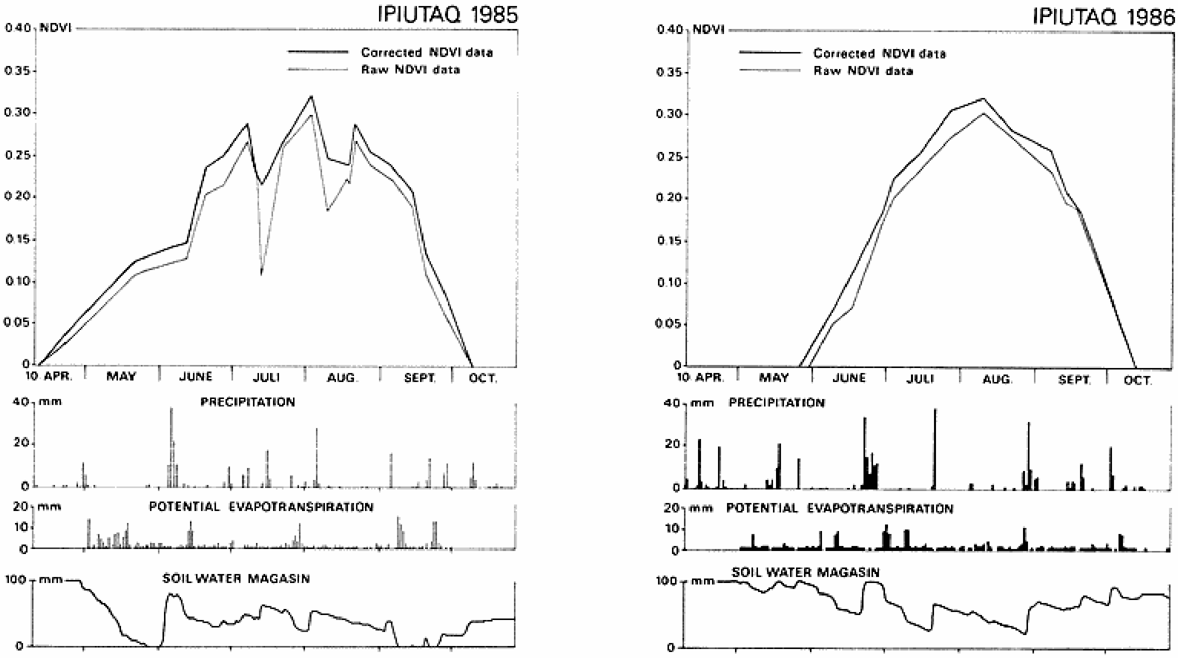

Fig. 5. Variation in raw and corrected NDVI data at Ipiutaq throughout the growing season 1985 and 1986. For comparison also daily values of precipitation, potential evapotranspiration and soil water magazine are shown.

technique was applied to produce a temperature mask, which was used to extract sufficient data for meaningful interpretation in spite of the cloudiness. The temperature mask was also used to remove snow and ice contamination of the data.

SEASONAL VARIATION IN NDVI

The seasonal NDVI-variation in 1985-1987 illustrated in figures 5 and 6 indicates that from an agricultural point of view the sheep-breeding district in Southern Greenland is very marginal. The growing season, defined as the period with positive NDVI, normally starts in mid-May and ends in the beginning of October. Taken as a mean for the pixels in a 5 by 5 km grid around the sheep farmstead of Ipiutaq, the NDVI-curve in 1986 showed a very normal progress with a typical maximum value of approximately 0.3 in the beginning of August. A few foehns during the growing season only influenced locations with a very poor soil water magazine (fig. 5).

In 1985, pasture started the growing season in mid-April after a very mild winter (figures 2 and 5). During May a number of foehns gave an evapotranspiration of 100 mm with a subsequent outdrying of the soil water magazine and a minor decline in the NDVI-curve. The period ended with 80 mm of rain within 4 days which, in combination with the start of the growing season for shrubs of willow and birch, allowed a fast NDVI-increase.

For comparison, the variations at Qagssiarssuk in 1985-1987 are given in fig. 6. It is clearly seen that in 1985 the growing season started nearly 1 $^1/_2$ months before normal because of the very mild winter and spring. All the years the maximum NDVI-value fluctuates just below 0.3 at the end of July and the beginning of August, and from the beginning of September the NDVI diminished toward zero in mid-October.

ESTIMATION OF BIOMASS PRODUCTION

The geograhical distribution of maximum NDVI in 1985, fig. 7, confirms the general impression of highest values close to the warmest part of the region at the bottom of the fjords. Compared to the figures given by Taylor (1985), these values of approx. 0.35 correspond roughly to 50 % of what can be found in a temperate climate.

The total accumulated wet biomass can easily be derived from the expression given in fig. 4. The maximum wet

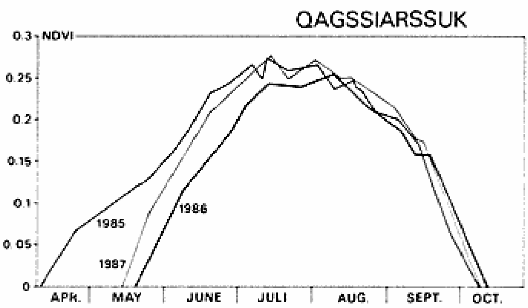

Fig. 6. Variation in corrected NDVI throughout the growing seasons 1985-1987 at Qagssiarssuk.

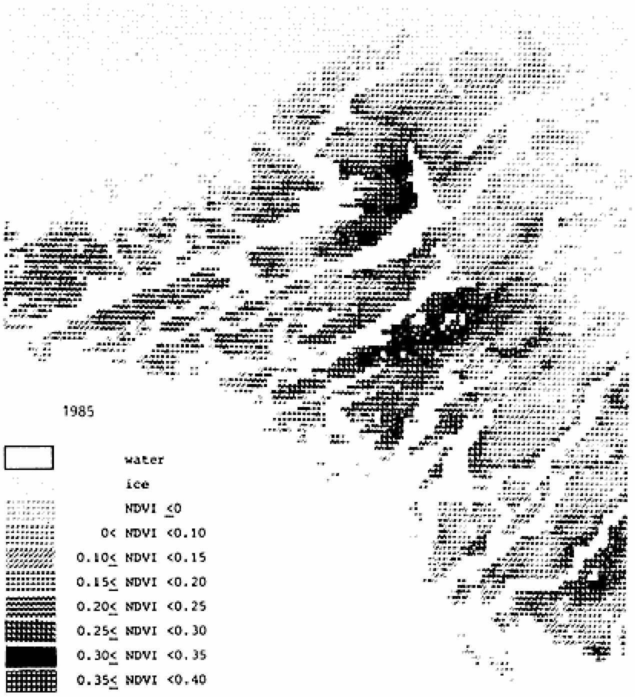

Fig. 7. Maximum NDVI during the growing season 1985.

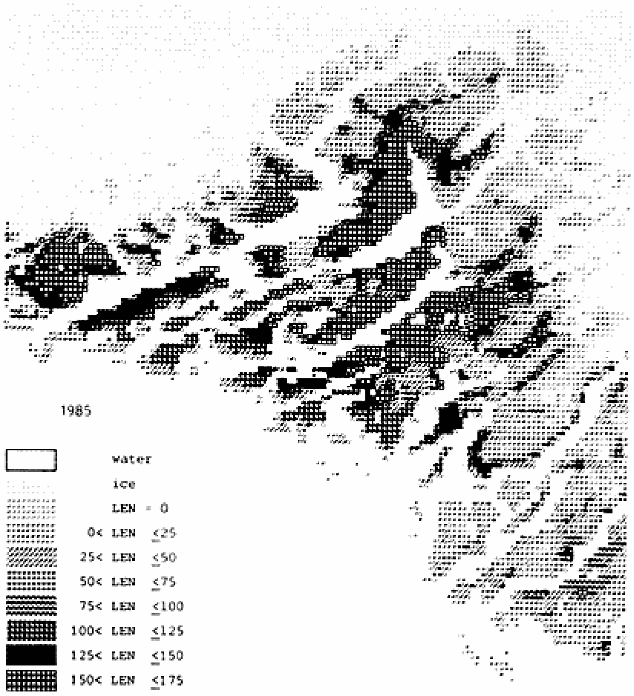

Fig. 8. Length of growing season (days) in 1985.

biomass accumulation integrated over a 1 km^2 NOAA pixel was thus found to be 800 kg/ha. The dry biomass production is approx. 50 % of the wet biomass production (Hansen & Søgaard, 1987). Because of great differences in the plants chlorophyll density and green-leaf biomass through the growing season the transformation in fig. 4 can only give an estimate of the biomass production at the optimum of the growing season, and this estimate is often slightly underestimated (Tucker et al., 1985).

The length of the growing season is also of great importance in a context of biomass production. Applying the definition of number of days with positive NDVI, this length can be found from the satellite imagery. The growing season in 1985 was found to vary between zero near the Ice Cap up to 150-175 days in the central region (fig. 8).

Because of the substantial spatial and temporal variability in the distribution of the green leaf biomass, the integrated NDVI-values during the growing season is a much better estimate for the potential biomass production in the area (Tucker et al., 1985), fig. 9. The time-integrated NDVI from 1985 shows maximum values of 30-32 at a number of sheepfarms with well-known high production and at a few remote locations. As it is impossible to find larger areas with a homogenous vegetation for estimation of the biomass production, it is necessary to use estimates from other parts of the world. As the transformation from NDVI to wet biomass production (fig. 4) was very similar to functions from the Sahel area, it is reasonable to use estimates from this area (Tucker et al., 1985), and incorporate the 50 % lower estimates from Greenland. The final function is:

$$P(\text{kg/ha/year}) = 0.5 \times 80 \times \text{iNDVI}$$

where iNDVI is the integrated NDVI in NDVI-days over the growing season, and P is the potential biomass production at the end of the growing season. The accuracy of the estimates is about 50 %. For Qagssiarsuk in fig. 7 the production can be estimated to 1160 kg/ha in 1985, 880 kg/ha in 1986 and 1080 kg/ha in 1987 (table 2). This is 20-50 % of the value obtained from the intensively cultivated infield, which normally covers an area of a few ha. Around the farmsteads the NOAA-AVHRR-pixel integrates both natural vegetation and agricultural field and is thus best suited for estimating the production of natural vegetation, used for summer feeding.

In general the long, warm summer in 1985 caused a very low biomass production in the coastal areas and in areas of high altitude due to insufficient soil water magazines, while in the Qagssiarssuk and Vatnaverfi areas with high soil water magazines the higher amount of solar radiation caused a biomass production extremely higher than normal (Hansen, 1987). In 1987 the summer was shorter but wet and warm, which caused a very high biomass production all over the area, except in the bottom of very well protected valleys, where a large amount of snow falling in April made a pronounced shortening of the

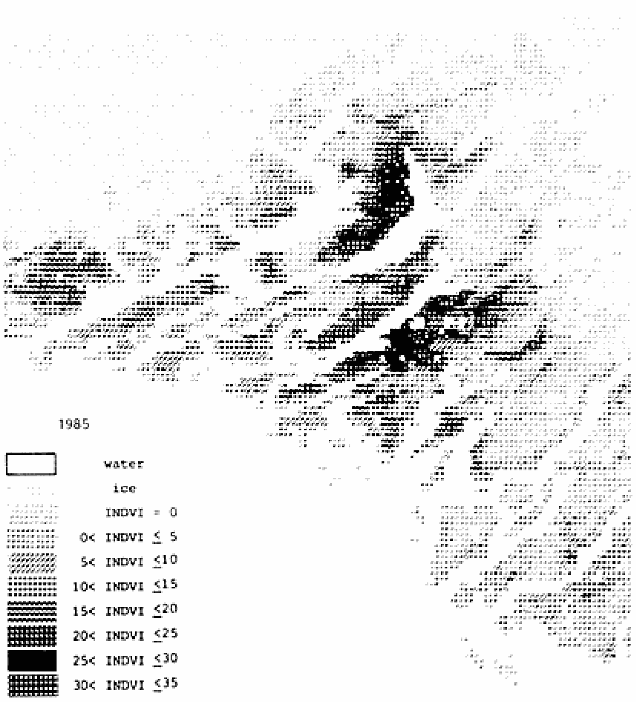

Fig. 9. Time-integrated NDVI during the growing season in 1985.

Year	Qagssiarssuk iNDVI	Qagssiarssuk kg/ha	Ipiutaq iNDVI	Ipiutaq kg/ha
1985	29	1160	32	1280
1986	22	880	27	1080
1987	27	1080	29	1160

Table 2. Time-integrated Normalized Difference Vegetation Index (iNDVI) and estimated biomass production.

growing season.

APPLICATION OF THE RESULTS

In the sheep-farming district of Southern Greenland summer grazing of the natural vegetation is the basis of the land use; during winter stall feeding is necessary. Mainly hay produced from small, level areas near the farms is used for feeding.

The Greenland Homerule has planned to keep approx. 130,000 sheep out on grass during the summer – corresponding to 50,000 sheep on stable during the winter. This is more than a doubling of the present number of animals, and with a yearly consumption per sheep of 0.5 ton of dry-matter during summer feeding and 0.2 ton for stable fodder during the winter a very accurate estimation of the potential biomass production is urgent, and here the satellite-based monitoring can be a useful tool to avoid overgrazing which, in this foehn-affected area, easily implies soil erosion. The operational satellite monitoring of the biomass production based on the NDVI approach is also a quick and low-cost method, and in combination with meteorological data it is possible to make forecasting of the dry biomass production, which explicitly can provide valuable assistance in the consolidation of sheep-breeding in Southern Greenland.

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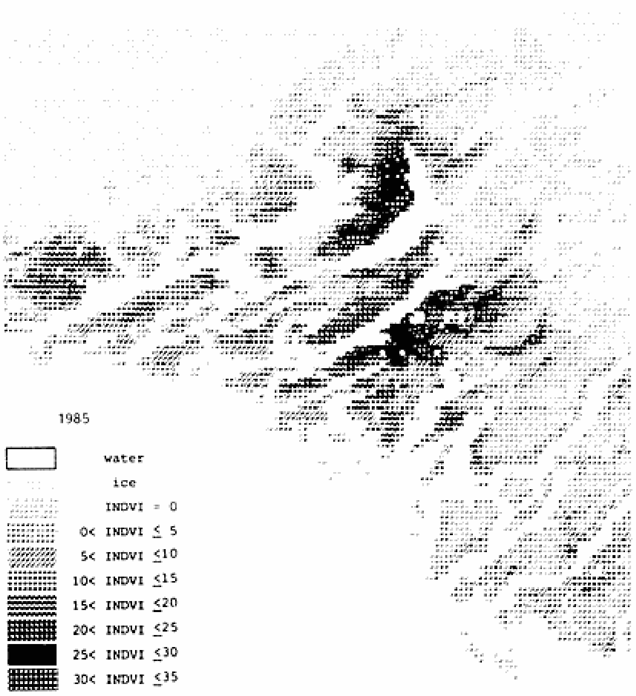

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