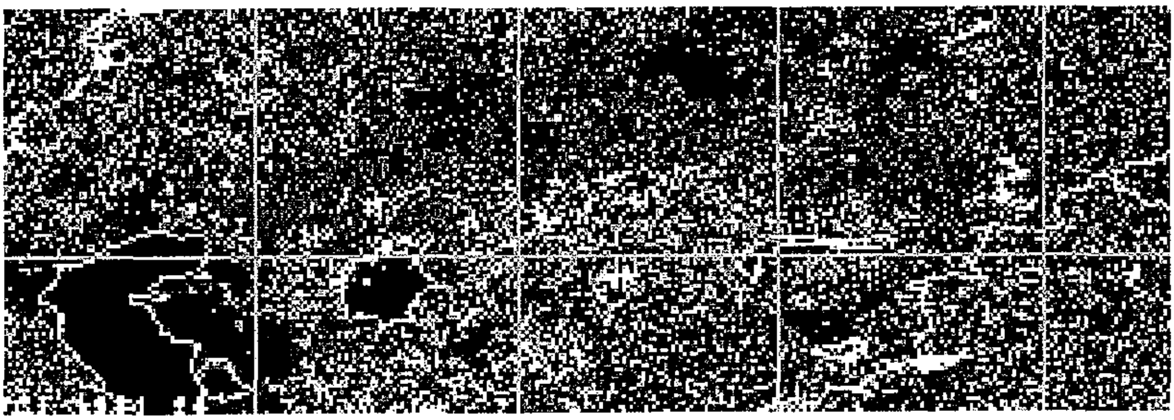
PN-ACM-154

Estimation of seasonal dynamics of arid zone pasture and crop productivity using AVHRR data
Phase II: Launching the Remote Sensing System

FINAL REPORT

Submitted to the Office of the Science Advisor
U.S. Agency for International Development



Principal investigators:

Dr. Anatoly Gitelson and Dr. Eilon Adar
J. Blaustein Institute for Desert Research, Ben-Gurion University of the Negev
Israel

Dr. Felix Kogan
National Environmental Satellite Data and Information Service
National Oceanic and Atmospheric Administration
USA

Collaborators:

Prof. Edige Zakarin*, Dr. Lev Spivak* and Lubov Lebed**
*Institute for Space Research, Academy of Sciences
**National Meteorological Administration
Kazakhstan

US-Israel AID/CDR/CAD program, Grant No. TA-MOU-CA17-956

April 2001, Beer Sheba

1. List of Figures

2. Table of Contents

PREVIOUS PAGE BLANK

3. Executive Summary

Most of Kazakhstan's pasture and cropland is located in arid and semi-arid zones with limited amounts of precipitation. Drought is the most typical phenomenon of the Kazakhstan climate, and occurs every two to four years. The climatic conditions of Kazakhstan cause a two to three fold variation in agricultural production from year to year and put considerable constraints on the Kazakhstan economy and its sustainable development. In order to mitigate harsh climatic and weather conditions, efficient management of water resources, and advanced estimation and planning of agricultural production are required. Fulfillment of these tasks is impossible without thorough monitoring of the crop environment and conditions, assessment of weather impacts, and estimation of crop and pasture production over a large area, drought detection and the monitoring of drought expansion, duration and impact.

Weather data are the primary sources of information used presently in Kazakhstan for monitoring the environment. Unfortunately, weather-watch systems have serious shortcomings due to insufficient density of weather observations and their scarcity in real time. The current economic situation in Kazakhstan puts additional constraints on conventional observation systems for monitoring the environment, because the number of weather stations is sharply decreasing and the quality of environmental observations is deteriorating

In this project, we developed

> *A non-conventional system that uses NOAA operational polar-orbiting satellites for quantitative assessments of pasture/crop conditions and productivity in Kazakhstan and monitoring Kazakhstan environment.*

The system includes:

- completely integrated and self-contained, High Resolution Picture Transmission receiving station with tracking antenna and positioner and receiver/demodulator/sectorizing subsystems;
- on-line PC for data collection and initial processing;
- hardware and software for data processing, storage and distribution;
- algorithms for converting satellite radiances into a Normalized Difference Vegetation Index Vegetation Condition Index (VCI), Temperature Condition Index, and Vegetation Health Index;
- algorithms for converting the vegetation indices into ground-derived environmental and agricultural characteristics such as: seasonal dynamic of pasture and crop conditions, their productivity, drought detection, and monitoring..

The developed algorithms were validated against ground measurements collected by conventional and remote sensing techniques in several areas of Kazakhstan with different climates and economic development.

The products of developed system are:

- Drought monitoring
- Monitoring of vegetation condition

- Remote estimation of sowing areas
- Forecast of pasture and crop productivity
- Monitoring of snow cover
- Monitoring of temperature distribution
- Monitoring of desertification processes

The results of this research used to improve monitoring of the environment, especially those conditions and phenomena that have an unfavorable impact on pasture and crop productivity. These results also helped to increase the accuracy of agricultural production estimates and provide better spatial and temporal coverage. Such improvements, in turn, helped to develop a more efficient system for management of water resources and to improve agricultural planning. Since satellite data collection has global coverage, this system might serve as a prototype for similar systems in other parts of the world where ground observations are limited or not available at all.

The results of this project helped Kazakhstan to start using new remote sensing technology for monitoring ___ environment. Software, and proposed concept and methods, provided a basis for a new, complete and efficient environmental monitoring and drought-watch system. This system is the main contributor to a program of early warning crop and pasture hazardous condition assessments and predictions of agricultural production. The findings of this project also helped to increase the accuracy of agricultural production estimates, spatial distribution of production and timeliness of delivery of these estimates to customers.

The main beneficiary institutions in Kazakhstan ___, first, our collaborators, the Institute for Space Research, and the National Meteorological Administration; other institutions to benefit include the Ministries of Agriculture, Environment, Water Resources and Kazakh Government.

All project goals were achieved. The non-conventional system, which uses NOAA operational polar-orbiting satellites for quantitative assessments of pasture and crop conditions and productivity in Kazakhstan, were launched. In addition, several other important tasks were accomplished:

- Remote estimation of sowing areas
- Monitoring of snow cover
- Monitoring of temperature distribution
- Calibration of satellite-derived indices versus ground data at experimental sites
- Monitoring of desertification

4. Research objectives and innovative aspects

4.1 Introduction

The Republic of Kazakhstan is the largest of the Newly Independent States (NIS) that formed following the Soviet Union's collapse. Located in Central Asia (Figure 1), Kazakhstan covers 2.7 million square kilometers, nearly four times the size of Texas and more than one-third the size of the conterminous US. Kazakhstan's geopolitical location (Rwykin 1998; Treyvish 2000) and ethnic diversity (Otarbaeva 1998; Schatz 2000a,b), have combined to yield a history rich in complex socio-political dynamics, including Tsarist and then Soviet colonization and domination of the region (Mandel 1942; Otarbaeva 1998). The Soviet era in Kazakhstan was marked by the establishment of vast state farms to serve as "grain factories" for the struggling Soviet economy (Ladejinsky 1938a,b; Opdahl 1960), increasing urbanization and industrialization of the region (Gurgen et al. 1999), and the use of eastern Kazakhstan for nuclear weapons testing (Sykes and Wiggins 1986; Sykes et al. 1993). The resulting environmental damage has been profound and diverse: from the widely recognized and studied problem of the recession of the Aral Sea (Micklin 1988; Kotlyakov 1991; Aladin et al. 1995; Petr and Mitrofanov 1998; Keyser et al. 1999) to radioactive and chemical soil contamination (Matzko and Butler 1999), long range transport of radioactive dust (Kuznetsova 1996), soil salinization (Funakawa et al. 2000), and PCB contamination of human milk (Lutter et al. 1998).

Since the collapse of the Soviet Union, Kazakhstan has undergone rapid and radical changes in socio-economic structures (Gurgen et al. 1999), including the emergence of oil and gas industries in partnerships with multi-national corporations and foreign governments (Grace 1998; Karibdzhanov and Taishibayev 1998), agricultural reforms (Gray 2000), and swift and broad shifts in land-cover. Kazakhstan is primarily rangeland: almost 70% of the land area is grazed by cattle, sheep, goats, and other livestock. A recent official study suggests two-fold a decrease in agricultural lands and state holdings and a nine-fold increase in settled areas (Kazakhstan Land Use Agency 1999). Marked decreases in livestock and meat production (Figure 2) accompanied by an increase in productive rangelands, as measured by vegetation indices (Terekhov et al. 2000), suggest that institutional change and its socio-economic consequences are primary drivers of the region's land-cover change. It is suggested that the demise of centralized economic policy has improved the status of previously threatened or stressed ecosystems, as in the case of Kazakhstan wetlands located along transcontinental migratory routes (Cresswell et. al. 1999). However, few details are known about the pace or extent of land-cover change, due to the collapse of regional environmental monitoring networks in the early 1990s. A major step toward re-establishing these monitoring networks was the installation of an AVHRR receiving station in 1995 (project Grant No. TA-MOU-CA13-056 was funded by USAID).

Figure 1. Map of Kazakhstan

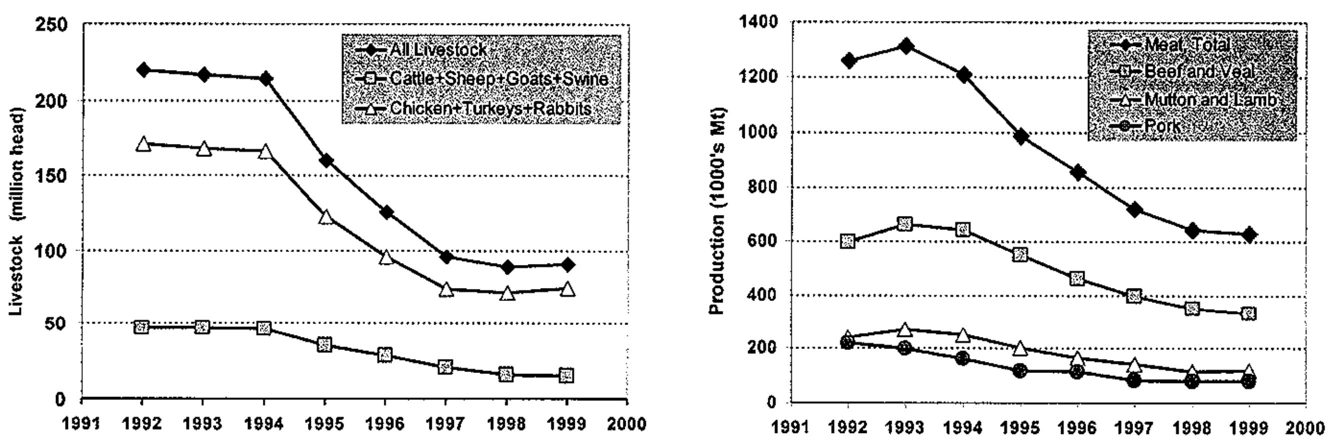


Figure 2. Change in livestock (l) and meat production (r) following change of government.

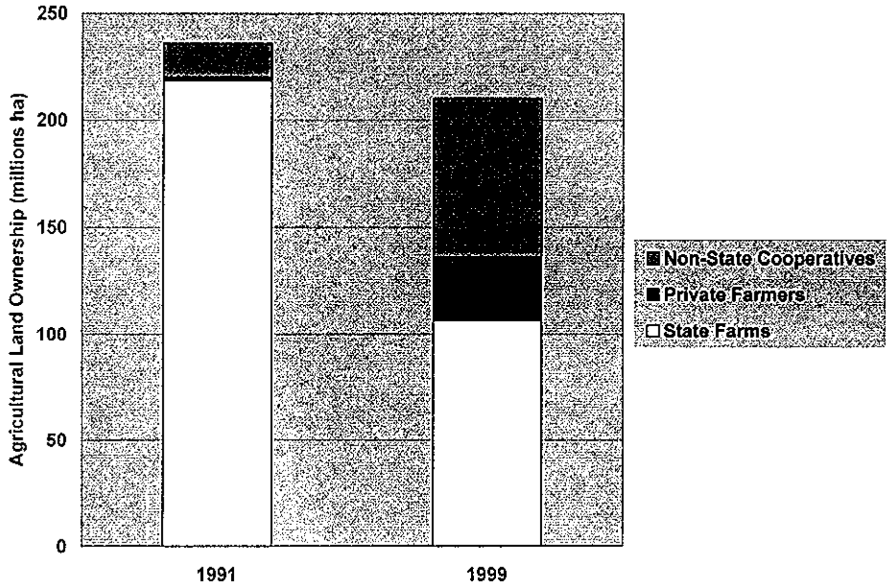


Figure 3. Change in agricultural land ownership following change of government.

Since achieving its independence in December 1991, the Republic of Kazakhstan has gone through a period of reconfiguring ownership policies for agricultural enterprises (Figure 3; Gray 2000) and property law for land. In this project we tried to reconstruct the pace and extent of recent land-cover change in the Kazakhstan region.

Broader Significance of Monitoring of Kazakhstan Environment

Anthropogenic disturbances to ecosystems sometimes come in the form of changes to institutions affecting land-use policies (Sanderson 1994). Certainly, the collectivization of agriculture and the establishment of state farms by the Soviets rapidly transformed the land-use and land-cover patterns across a vast area of Eurasia (Ladejinsky 1934a,b; Ladejinsky 1938a,b). Furthermore, centralized decision-making can increase enhanced land-cover variability. Brada (1986) found that agricultural production in socialist economies exhibited significantly higher interannual variation for many crops during the period 1945-1981 as compared to 1920-1938 than could be explained by variations in yield or climate.

The political changes associated with the demise of socialist governments across Central and Eastern Europe and Asia at the end of the 1980s and beginning of the 1990s triggered a major and ongoing episode of widespread land-cover and land-use change (LCLUC). This sudden regional transformation of institutional constraints on land-use constitutes a great but largely unrecognized "experiment of opportunity" for the global change community. Kazakhstan is well suited to serve as a model for the study of institutional change driving LCLUC change and as a model for multi-resolution spatio-temporal analysis of land-cover dynamics because (1) it is vast in size but dominated by a single land use (grazing), (2) it offers smooth gradients of climatic conditions, (3) it is poised for desertification under climate warming, (4) it exhibits diverse but spatially localized environmental problems, and (5) it is witnessing increased urbanization and industrialization in the era of satellite remote sensing, motivated in large part to the development of the region's mineral wealth including considerable reserves of oil and natural gas (Grace 1998; Karibdzhanov and Taishibayev 1998).

Results of Prior Work

Project "Estimation of seasonal dynamics of arid zone pasture and crop productivity using NOAA/ AVHRR data". US-Israel USAID/CDR/CAD program, Grant No. TA-MOU-CA13-056. Ben-Gurion University of the Negev, Israel, Institute for Space Research, Kazakh Academy of Sciences. 1995-1997. PI: A. Gitelson (BGU) and F. Kogan (NESDIS/NOAA).

Most of Kazakhstan's pasture and cropland is located in arid and semi-arid zones with limited amounts of precipitation. Drought is a frequent event in the Kazakhstan climate, occurring every two to four years. These climatic conditions cause a two to three fold interannual variation in agricultural production (Figure 4), thereby placing considerable constraints on the Kazakhstan economy and its sustainable development. In order to mitigate harsh climatic and weather conditions, efficient management of water resources and advanced estimation and planning of agricultural production are required. Fulfillment of these tasks is impossible without thorough monitoring of the crop environment and conditions, assessment of weather impacts, and estimation of crop and pasture production over a vast region, drought detection as well as monitoring of drought expansion, duration, and impact.

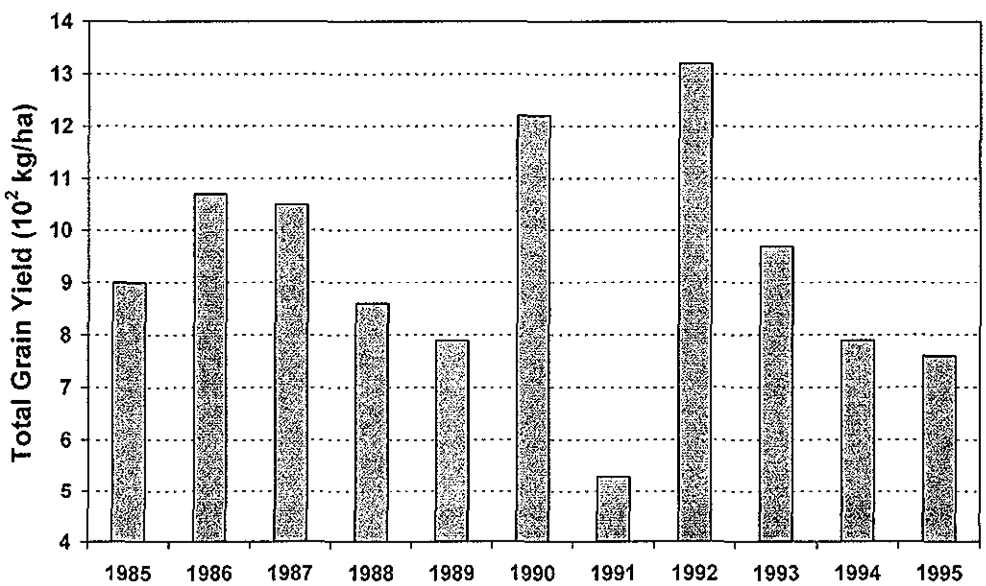


Figure 4: Interannual variation in total grain yield in Kazakhstan.

At present, weather data are the primary sources of information widely used to monitor the environment. Unfortunately, weather-watch systems have serious shortcomings because weather data characterize point locations rather than an area, and meteorological stations are not equally distributed. The problem of the low density of weather station becomes especially acute in areas with marginal climatic resources such as Kazakhstan. In addition, weather data are quite often not available in real time or they are incomplete due to political, economic, or even just communication problems. The current economic situation in Kazakhstan puts additional constraints on the conventional system for monitoring the environment because the number of weather stations is sharply decreasing and the quality of environmental observations is deteriorating.

Observations from meteorological satellites routinely provide more complete, timely and much better spatial coverage of the earth's surface and environment than do weather stations. Over the past decade, satellite-derived vegetation indices, particularly those which are derived from NOAA polar orbiting operational satellites, have shown excellent potential for monitoring vegetation, and environmental parameters and phenomena (Tucker et al., 1985; Marlingreau, 1986; Prince & Tucker, 1986; Townshend et al., 1986; Tucker et al., 1986; Justice et al., 1986; Rao et al., 1990; Ohring et al., 1989; and NOAA, 1988, Kogan, 1987, 1995a, b). Presently, a considerable amount of the AVHRR-based data are archived and can be used for monitoring weather impacts, assessment of crop and pasture environment and conditions, and for estimating crop and pasture production.

However, in order to use the NOAA operational satellite data in Kazakhstan it was necessary to adjust them to local conditions, to parameterize the equations, to develop algorithms for data correction, calibration and use, to validate the results and to transfer new technology. This project provided answers to all of these problems.

As the result of this project, we developed the scientific principles for a non-conventional system that uses NOAA operational polar-orbiting satellites for quantitative assessments of pasture/crop conditions and productivity in Kazakhstan. The system includes receiving station, an online PC for data collection and initial processing; hardware and software for data processing, storage and distribution, algorithms for converting satellite radiances into the NDVI and the Vegetation Condition Index (VCI), and algorithms for converting the NDVI and the VCI into ground-derived environmental and agricultural characteristics including seasonal dynamic of pasture and crop conditions, their productivity, drought detection, and monitoring. Almost invariant across ecological backgrounds (soil type, geology, etc.), VCI is primarily dependent upon weather conditions. It estimates the response of vegetation state to weather across very different ecological and climatic conditions.

4.2 Objectives

The overall goal of this project was to launch a system for receiving NOAA/AVHRR data and real-time monitoring drought and crop and pasture conditions and productivity.

Our specific objectives include the following:

- develop NOAA/AVHRR satellite data base for the entire Kazakhstan 1985 till 2000;
- validate the algorithms for major crop- and pasture-producing regions of Kazakhstan;
- use NOAA/AVHRR thermal channels for improvement of the reliability of the developed algorithms;
- illuminating land-cover dynamics during the "shrouded period" of transition, viz. 1992-1995;
- demonstrating an innovative method for remote monitoring of Kazakhstan environment.

4.3 Strengthening the Scientific and Technical Capacity of Kazakhstan

This project combines scientific and operational aspects of remote sensing, agricultural meteorology, agronomy, soil physics, and management and optimization of water use. It promoted the use of advanced remote sensing scanners, computing methods and PCs for accurate and timely estimation of pasture and crop productivity in arid zones. The remote sensing methods and techniques employed in Kazakhstan extended the application techniques towards efficient use of water in agriculture and arid zone pastures. This work has strengthened collaboration between the developing country and countries with advanced technologies.

Most of the work was conducted in Kazakhstan. Drs. E. Zakarin and L. Spivak (Kazakhstan) managed the installation and operation of the satellite receiving station and the hardware for recording, processing, and achieving the data. They and Dr. L. Lebed managed collection of ground-truth data both from the test fields and from conventional sources in Kazakhstan. Researchers from Kazakhstan visited Israel to learn new technologies. Remote sensing data from a large area were collected in the USA from NOAA's archive of the Global Vegetation Index (GVI) data set. Drs. A. Gitelson (Israel) and F. Kogan (USA) transferred technologies and trained Kazakh specialists in system development and application. They also participated in training the staff how to measure spectral characteristics of vegetation and atmosphere, using instruments belonging to the J. Blaustein Institute for Desert Research (Israel).

4.4 Innovative aspects

For the first time satellite operational technologies were applied to

- operational estimation of crop and pasture conditions and productivity over a large areas with different ecological and climatic zones in Kazakhstan;
- drought detection and monitoring in an area of extreme continental climate;
- the developed algorithms were validated against ground measurements collected by conventional and remote sensing techniques over a large areas of Kazakhstan;
- NOAA/AVHRR data base was developed for whole Kazakhstan from 1985 till 2000;
- NOAA/AVHRR thermal channels was used for improvement of the reliability of the developed algorithms;
- algorithms for crop and pasture productivity prediction based on NOAA/AVHRR data were developed;
- operational system for monitoring snow cover was launched.

5. Methods and Results

5.1. Vegetation as an indicator of the environment

Vegetation is the most important part of land ecosystems. Climate, soil, geographic features and ecological resources influence vegetation, changing its productivity and distribution and largely determine the vegetation type and amount in a given region.

On a short-term basis, changes in vegetation are mainly controlled by weather fluctuations. Vegetation responds to environmental changes through redistribution of the energy and water fluxes inside the atmosphere-vegetation-soil continuum. Transpiration and evaporation are the most important processes that control the partitioning of net radiation into latent and sensible heat fluxes and redistribution of water between surface run-off and infiltration. The latter processes regulate the amount and movement of water in the soil and, finally, its availability to vegetation. Uninterrupted flow of water in the soil creates an environment for development of root systems and delivery of water to leaves. This, in turn, activates evapotranspiration, reduces sensible, and increases latent, heat fluxes and stimulates a healthy environment for excellent growth and high productivity of vegetation. Lack of water in the soil causes the opposite flow of processes, leading to an unhealthy environment and, consequently to low productivity of vegetation. Thus, the state of vegetation and changes in this state, act as a signal vis-a-vis vegetation condition and production and indirectly characterize environmental conditions.

One of the most attractive properties of vegetation is its ability to reflect past environmental conditions. These accumulated conditions alter the flow of physiological processes that, in turn, lead to the changes in vigor, density, and greenness of vegetative surface. The possibility to estimate antecedent conditions as they are reflected in vegetation appearance is especially useful for the assessment of cumulative environmental impacts, necessary for forecasting vegetation growth, development, and production.

5.2 Satellite data

Radiances measured by the Advanced Very High Resolution Radiometer (AVHRR) on board NOAA-9, 11, and 14 polar-orbiting spacecrafts were used in this study. These data were collected from Receiving Station in Almaty (1 km spatial resolution) and from the NOAA/NESDIS Global Vegetation Index (GVI) product developed from April 1985 (Kidwell 1997). The GVI is produced by sampling and mapping the AVHRR-based 4-km (global area coverage format, GAC) daily radiances in the visible (VIS, 0.58-0.68 µm), near infrared (NIR, 0.72-1.1 µm), and infrared (IR, 10.3-11.3 and 11.5-12.5 µm), which were truncated to 8-bit precision, and mapped to a (16 km)^2 latitude/longitude grid. To minimize cloud effects, these maps were composited over a 7-day period by saving radiances for the day that had the largest difference between NIR and VIS (Kidwell 1997). The reflectances in the VIS and NIR and emission in the IR (CH4, 10.3-11.3 µm) were used here.

The GVI-based radiances are known to have both inter-annual and intra-annual noise due to variable illumination and viewing conditions, sensor degradation, satellite navigation and orbital drift, atmospheric and surface conditions, methods of data sampling and processing, communication and random errors (Gutman 1991; Goward et al. 1991; Townshend, 1994; Los et al., 1994; Justice &

Townshend., 1994). Therefore, noise removal is crucial for data use. The initial processing included post launch calibration of VIS and NIR following Rao and Chen 1995, 1999, calculation of NDVI

NDVI= ([NIR-VIS]/[NIR+VIS]),

and converting the CH4 radiance to brightness temperature (BT), the later was corrected for non-linear behavior of the sensor (Kidwell 1997; Weinreb et al 1990). As the result, a long-term noise and shifts between the satellites in radiances and NDVI were reduced substantially. Correction of BT for satellite orbital drift was not available, accordingly, BT is decreasing with the aging of satellites. However, in vegetation-type ecosystems, which are the main interest of the paper, this decrease is much smaller than the BT changes related to weather impacts on ecosystems. This statement is supported by strong correlation between ecosystem productivity and BT (Kogan 1997, Unganai and Kogan 1997).

5. 3 Principles of vegetation status estimation

The spectral reflectance of completely covered green vegetation is mainly dependent on leaf pigments, internal leaf/canopy structure, and water content. In the VIS band, amount of chlorophyll determines mainly reflected solar radiation (Gates 1970, Gitelson and Merzliak 1997) and in the NIR to middle IR bands, the internal leaf scattering mechanisms, mesophile composition, canopy architecture, and water content control upwelling radiances (Myers 1970, Gates 1970). The IR emission is directly dependent on the temperature of a vegetation canopy and indirectly on water content in the plants (Gates, 1970) and can be used as a proxy of changing vegetation condition. Following these properties, the NDVI and CH4-based BT (CH4 is less responsive to atmospheric water vapor than CH5) are ideal for monitoring vegetation greenness and vigor and through them vegetation condition and health (Tucker 1979, Townshend and Justice 1986, Justice et al 1986; Tucker and Choudhury, 1987; Goward and Dye 1987; Kogan, 1990; Cracknel 1997). They were used in the development of indices characterizing temperature, moisture, vegetation health conditions, and though them vegetation productivity (Kogan 2000; Kogan 1995b, 1997, Unganai and Kogan 1998).

The three-channel algorithm consists of comprehensive processing of NDVI and BT, which includes complete removal of temporal high frequency noise, stratification of world ecosystems, and detection of medium-to low frequency fluctuations in vegetation condition associated with weather variations (Kogan, 1995a, 1997, 2000). These steps illustrated in Figure 5, are crucial in order to use AVHRR-based indices as a proxy for temporal and spatial analysis and interpretation of weather-induced vegetation condition and health.

An example of frequent and fast changes (up and down from one week to another) in NDVI and BT shown in Fig. 5a, are generally not coherent with a regularly slower change in vegetation greenness, vigor, and health in response to weather variations. These fluctuations are due to varying transparency of the atmosphere (clouds, aerosols etc.), viewing geometry (satellite and sun angles), bi-directional reflectance, etc. and create fundamental constraints for monitoring vegetation and land surface condition.

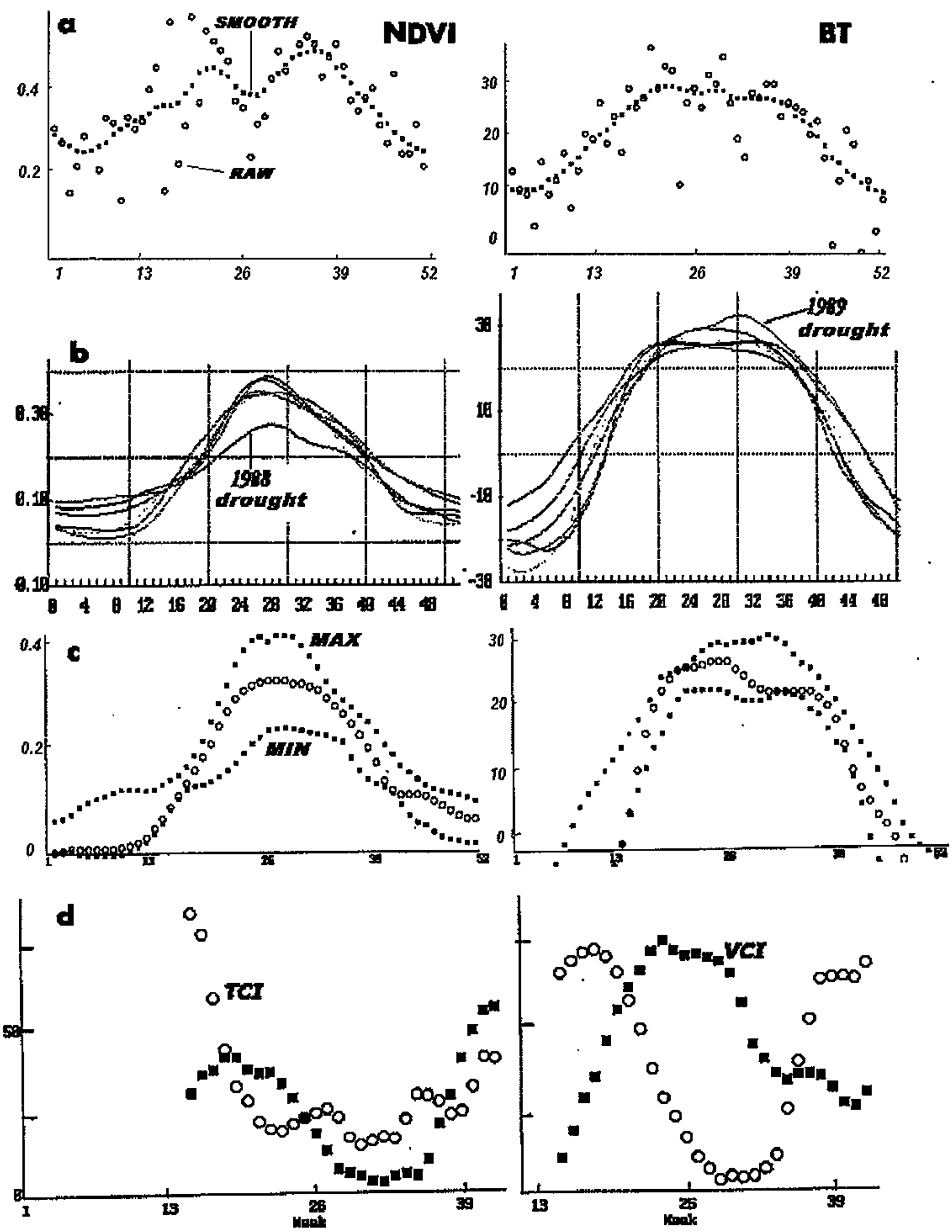


Figure 5. Explanation of the major steps in algorithm development. (a,b,c) Left panels: NDVI, right panels BT (°C) for one 16-km pixel (United States); (a) raw (circle) and smooth (filled box) data (35°N, 81.8°W); (b) 1986-1991 annual time series (40.6°N, 100.6°W); (c) MAX-MIN time series (filled box) as an indicator of ecosystem "carrying capacity" and 1993 time series (circle:48°N, 100°W); (d) VCI and TCI time series (left: 40°N, 90°W; right: 34°N, 82°W). From Kogan (2000).

Physical models and threshold techniques presently available can eliminate a small portion of these jumps. Therefore, an alternative method was used to remove them statistically by smoothing NDVI and BT time series with a combination of compound median filter and least square techniques (Velleman and Hoaglin 1981, van Dijk et al 1987, Kogan and Sullivan 1993). As seen in Fig. 5a, the filtering helps to approximate annual vegetation and temperature cycles, completely suppress outliers and, more important, enhance medium (several weeks) and low-frequency (several months) variations (hills and valleys) related to weather change (consistent reduction of NDVI from week 20 to 26 with the following recovery).

After smoothing, weather-dependent inter-annual differences in NDVI and BT become apparent; as seen in Fig. 5b, NDVI is lower (reduced vegetation greenness) and BT higher (thermal stress) in drought versus wet and normal years. The principle of comparing a particular year NDVI and BT with other available year values (for the same pixel and week) was laid down in the next stage of the algorithm development. Accordingly, for each pixel and week, the range of NDVI and BT variation was calculated from the 14-year maximum and minimum (MAX-MIN) values (Fig. 5c). The assumption was that (MAX-MIN) characterizes the extreme NDVI- and BT-based vegetation state associated with extreme weather impacts. These criteria were used to describe and classify, weather-related ecosystems' "carrying capacity" and assisted in establishing NDVI and BT signatures such as annual curve shape, curve dynamics during leaf appearance and senescence, the range of changes, and partitioning of NDVI and BT values into ecosystem and weather components (Kogan 1997, 1995a). The analyses indicate that for vegetative ecosystems, weather contribution is smaller than the ecosystem and they should be separated in order to use weather component for monitoring vegetation health and condition (Kogan 1995). Therefore, an important step in algorithm development was to single out weather components based on MAX-MIN criteria.

After the thresholds were set up, the NDVI- and BT-based vegetation condition and health were estimated relative to the MAX-MIN interval for each pixel and week (Fig. 5c). If NDVI and BT for a particular week of a year are half way between the MAX and MIN, vegetation condition is estimated at average level; if NDVI is close to the MIN and BT to the MAX, conditions are stressed; for the opposite combination they are favorable. This was formalized by the following three indices (equations 1-3): Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health index (VH). They describe moisture, thermal and vegetation health conditions, respectively. Since the NDVI and BT interpret oppositely extreme weather events (for example, in case of drought, the NDVI is low and BT is high due to both vegetation deterioration and higher contribution of a soil signal; conversely, in a non-drought year, the NDVI is high while BT is low), equation (2) was modified to reflect the same direction of the impact.

$$VCI = (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min})*100 \quad (1)$$

$$TCI = (BT_{max} - BT) / (BT_{max} - BT_{min}) * 100 \quad (2)$$

$$VH = a*VCI + b*TCI \quad (3)$$

where NDVI, $NDVI_{max}$, and $NDVI_{min}$ are the smoothed weekly NDVI, its multi-year absolute maximum and minimum, respectively; BT, BT_{max}, and BT_{min} are similar values for brightness temperature; a and b are coefficients quantifying a share of VCI and TCI contribution in the combined condition. For example, if other conditions are near normal, vegetation is more sensitive to moisture during canopy formation (leaf appearance) and to temperature during flowering. Therefore, the share of moisture contribution into the total vegetation condition (health) is higher than temperature during leaf canopy formation and lower during flowering. Since moisture and temperature contribution during a vegetation cycle is currently not known, we assume that the share of weekly VCI and TCI is equal.

Finally, an example in Fig. 5d illustrates two of many possible combinations of VCI- and TCI-based vegetation and temperature conditions. Extremely unhealthy conditions are normally associated with coincidence of both severe moisture and thermal stress (both VCI and TCI approaching zero; left figure). The right figure shows that vegetation experienced severe thermal stress, while moisture conditions were fair/favorable. Stressful conditions related to only one of the indicators provide some warning, especially if stress is moisture-related.

5. 4. Algorithm validation

Ground measurements were collected from weather station observations and measurements in field experiments. Weather observations were obtained from 69 stations during the 1985-1999 period. Weather observations included 10-day total precipitation (mm) and average temperature (^oC), end of 10-day soil moisture (mm), phenology and density of vegetation (number of plants per square meter).

During the growing seasons of 1997 and 1998, the biomass of winter wheat and spring barley (three plots) was measured at station Aksinger, 36874 (Almaty), and that of grass at four plots of station Aidarly, 36819 (Almaty). Simultaneously with biomass, radiance was measured with hand-held and airborne radiometers. These measurements were made in the spectral bands corresponding to Ch1 and Ch2 of the AVHRR sensor. The NASA-designed hand-held radiometer was used to measure upwelling radiance of vegetation and a reference plate. The reflectance of vegetation was determined as a ratio of crop to plate radiance. The reflectance was measured in twenty different locations of each plot and average and median values were calculated.

For comparison to ground data, mean VCI was calculated from 3 by 3 GVI pixels around selected weather stations. We calculated the highest ($NDVI_{max}$) and the lowest ($NDVI_{min}$) values of the NDVI during 1985-1994 for each of the 52 weeks of the year and for each pixel. The resulting maximum and minimum NDVI were used as the criteria for estimating the upper (favorable weather) and the lower (unfavorable weather) limits of the ecosystem resources. These limits characterize the "carrying capacity" of each selected station ecosystem. Since the minimum and maximum NDVI curves delineate the contribution of ecosystem component in the NDVI value for the cases with the most extreme weather, the area between these curves largely approximates the weather-driven component of the NDVI .

In 1985-1999, density of vegetation (D) was measured every ten to twenty days during the growing period as number of plants (spring wheat) per square meter. To compare to VCI, density of vegetation was expressed as a deviation of D from multi-year median value (D_{med}), normalized to difference between 1985-1994 maximal (D_{max}) and minimal (D_{max}) densities:

$$DD = (D-D_{med})/(D_{max} - D_{min}) \quad (4)$$

Status of vegetation in the 1991 and 1992 growing seasons were quite similar in some locations and different in others. At the general background of NDVI similarity for 1991 and 1992 growing seasons, the VCI were extremely different (Figs. 6 and 7). The VCI was more sensitive to change in vegetation conditions compare to NDVI. The density deviations (DD) were compared with VCI dynamics during 1991 and 1992 for the selected stations (Fig. 8). There is a very good match between the VCI and DD, although the dynamics of vegetation conditions was quite different between years, stations, and period of vegetation development. Analysis of temporal variations in Fig. 8 shows that there is a strong relationship between the VCI-derived vegetation condition and change in density of wheat per unit area. Determination coefficient (r^2) for individual stations changes from 0.72 to 0.92 with an error of density estimation between 11 to 15 per cent. However, the strongest correlation is observed for VCI values between 0 and 80. For higher VCI values, there is a tendency towards decrease in a slope of VCI versus DD relationship. This supports previous findings of NDVI saturation for high chlorophyll content, leaf area index and canopy cover (e.g., Gitelson and Merzlyak, 1994a,b; Gitelson et al., 1996).

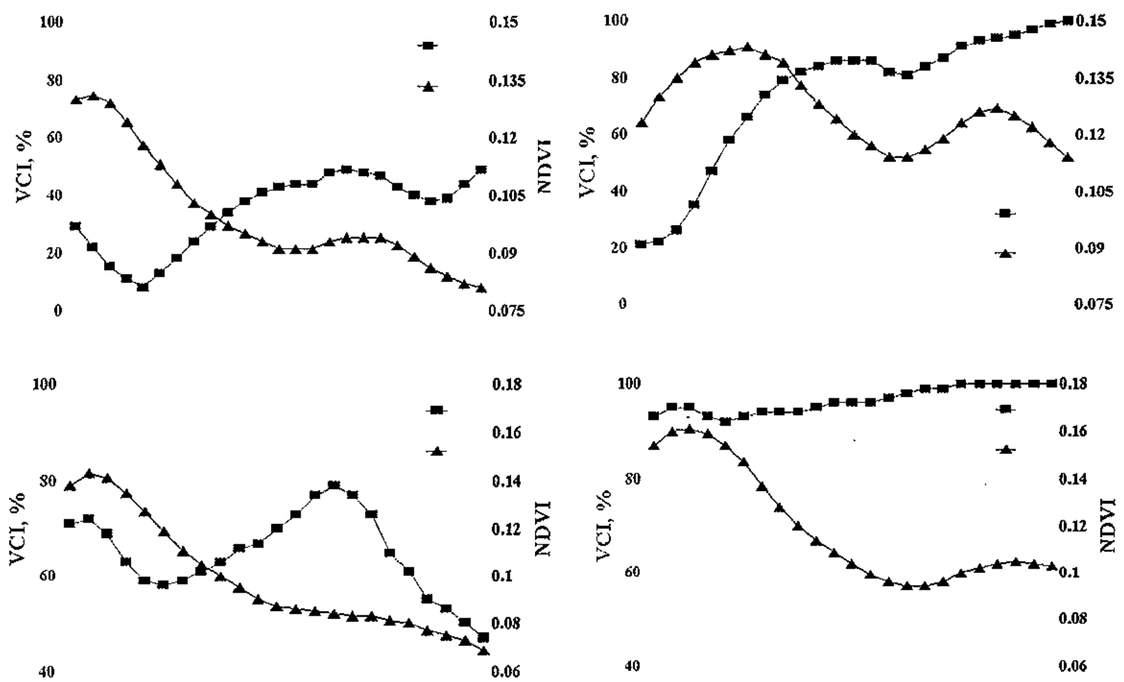


Fig 6. NDVI and VCI dynamics at three stations during 1991 (dry) and 1992 (favorable) conditions

The correlation between the VCI and density deviation for all six stations used in this research is shown in Fig. 9. As seen, VCI values around 50, which characterize near normal vegetation condition corresponds to multi-year median value of vegetation density (DD near zero).

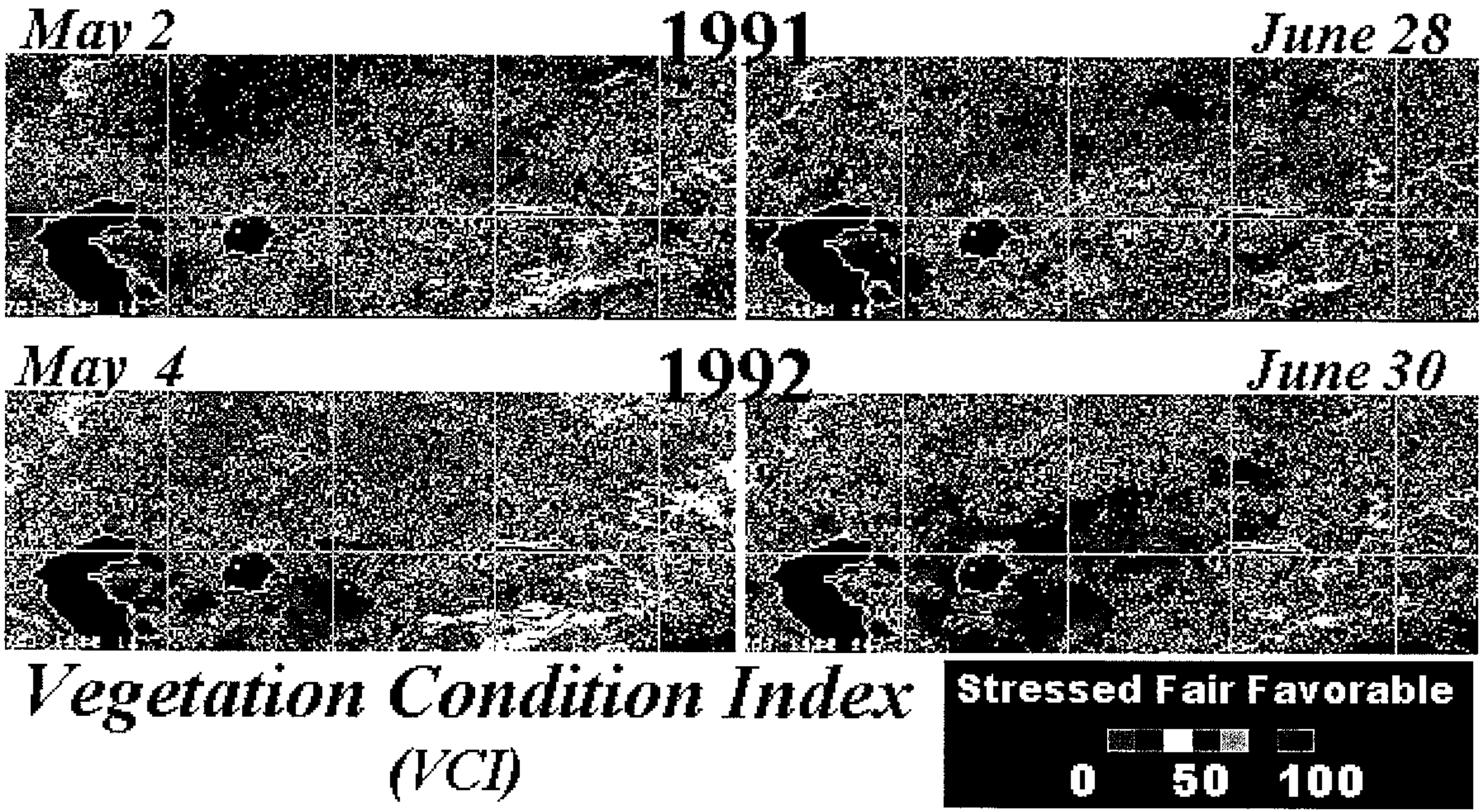


Figure 7. VCI for 1991 and 1992 derived from AVHRR data

VCI values below 30, which was shown specify drought conditions (Kogan, 1995), correspond to the density of vegetation below - 20. The lowest density of vegetation observed in this study was around - 60 with a matching VCI value around 10. For VCI over 50, density of vegetation exceeds median value, indicating that conditions are favorable for development of healthy vegetation.

Despite the fact that the selected stations were located in different climatic and ecological zones, all station points were located around the same correlation line (Figure 9). Although there are some differences between the stations, correlation was high ($r^2 = 0.76$) with an estimating error of DD less than 16 per cent for a very high variation of vegetation density (between 60 and 70%). This error is less for low density, indicating that in cases of very unfavorable weather (such as drought) the accuracy of VCI-derived estimates is higher.

The main causes for scattering of the VCI versus variation of vegetation density relationship are: (a) the difference between large-scale estimate of VCI from AVHRR data (3 by 3 GVI pixels) and field scale (1 by 1 km) measurements of vegetation density; (b) reduced sensitivity of NDVI and VCI to high values of vegetation biomass and density; (c) limited period of NDVI and vegetation density observations for accurate retrieval of ecosystem resources.

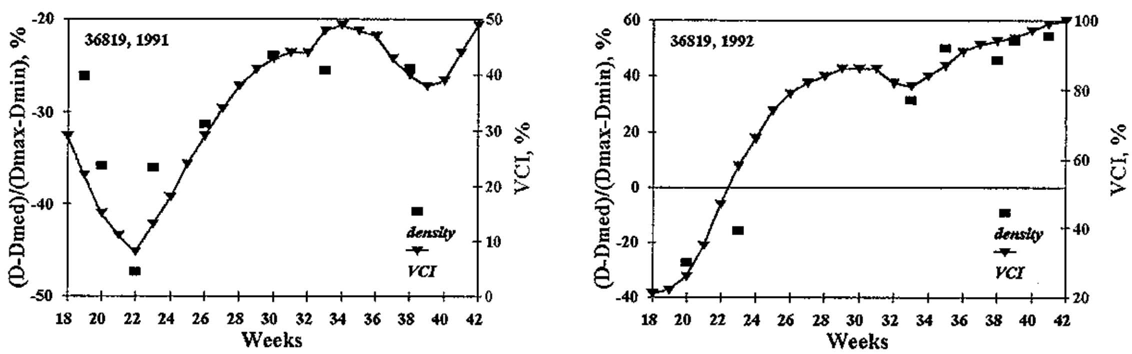


Figure 8. Comparison of the VCI and multi-year density variation from median values in 1991 and 1992.

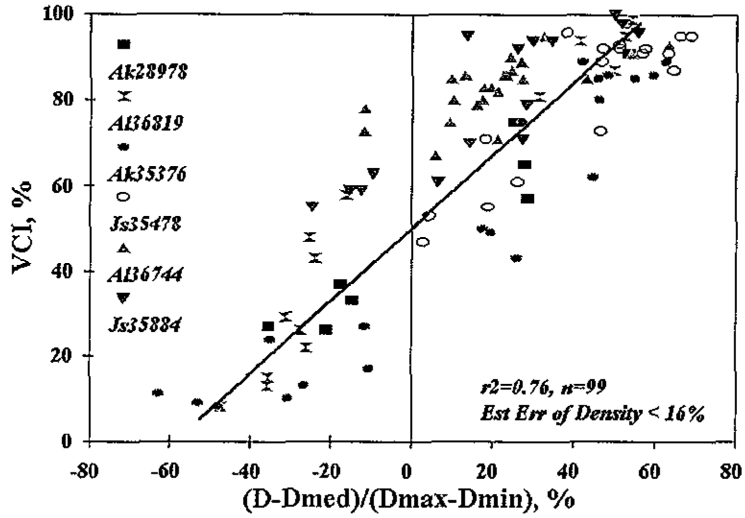


Figure 9. The VCI-derived and actually measured density of vegetation for six stations in 1991 and 1992.

5.5 Monitoring vegetation conditions

The results of section 5.4 above clearly indicat that the vegetation indices could be converted into biomass values of crop and pasture measured at the experimental plots. This conclusion alone answered one of the important project objectives that remote sensing data can be successfully used for monitoring vegetation productivity and environmental conditions. Crops and rangeland occupy nearly 200 million hectares of Kazakhstan and are located in very different climatic and ecological zones. Precipitation fluctuates from 100 mm in desert areas to more than 1000 mm in foothills. The NDVI cannot be used for vegetation monitoring over a large area with extremely diversified environmental conditions and consequently, vegetation productivity. Therefore, the attempt was made to find out whether AVHRR-derived VCI could be used as an indicator of vegetation productivity on a large area.

Since 1997, monitoring vegetation conditions of Kazakhstan in near real-time was established. Every Monday, satellite data were extracted for the Kazakhstan region from the Global Vegetation Index Product, were processed and the VCI was calculated. These VCI data were used for assessment of vegetation conditions. It is important to note that since 1995 data have been collected from the new NOAA-14 satellite, which became operational in mid-February. Additional procedures have been applied for data calibration.

Vegetation status was monitored using NOAA/AVHRR data with high spatial resolution. Each week maps of vegetation status were produced. In Figures 10-13 examples of VCI, TCI, and VH maps for different seasons are presented. In Fig. 14 comparison of Vegetation Health for Kustanay region is shown. Vegetation health was highest in 1999. While temporal behavior of vegetation health in 1999 and 2000 were quite similar, in 1998, vegetation health in weeks 20 to 36 was significantly lower. The maps of vegetation health were presented to Ministry of Agriculture and Environment of Kazakhstan and helped them in decision-making.

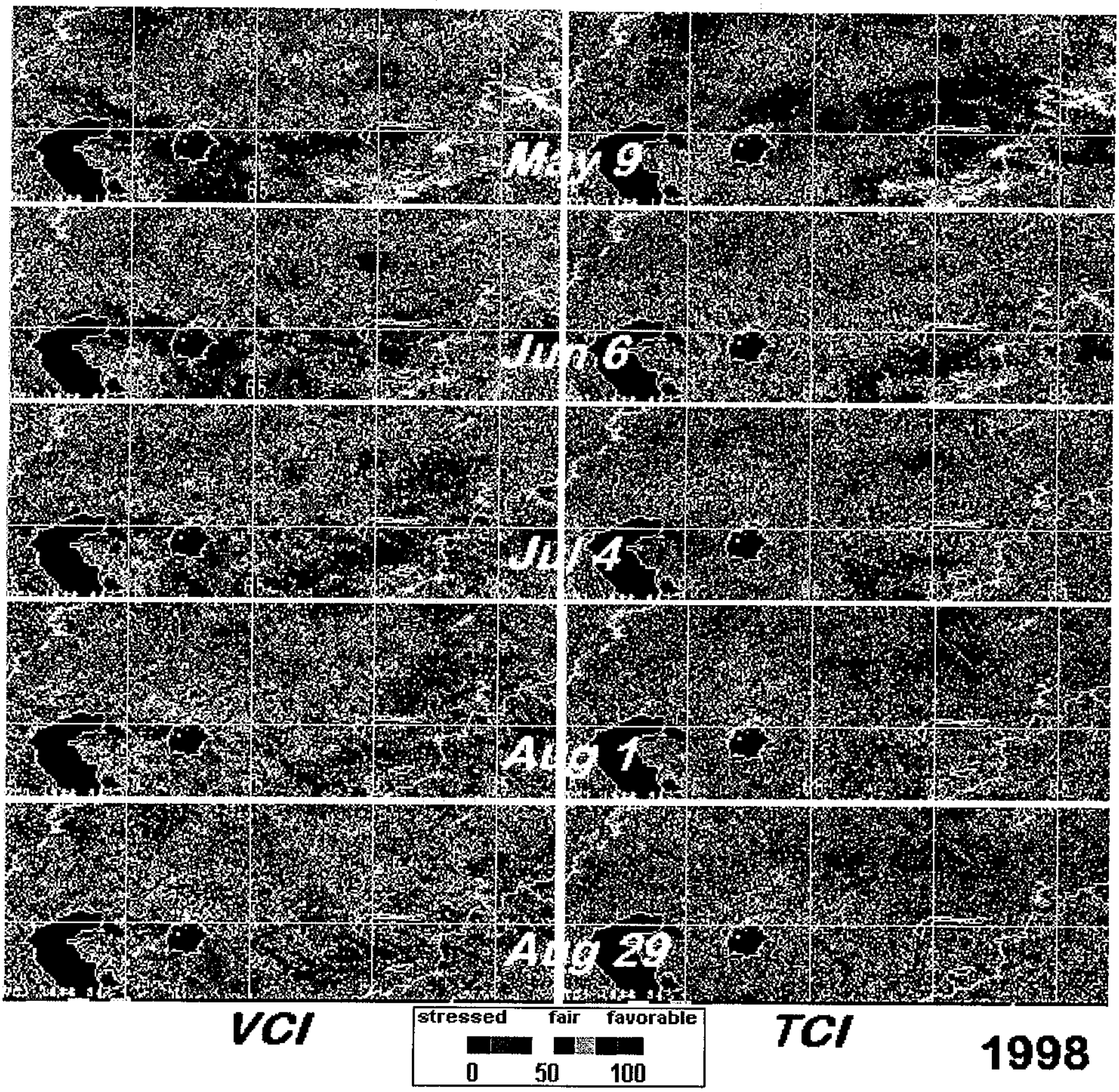


Figure 10. Maps of VCI and TCI indices, retrieved from AVHRR data

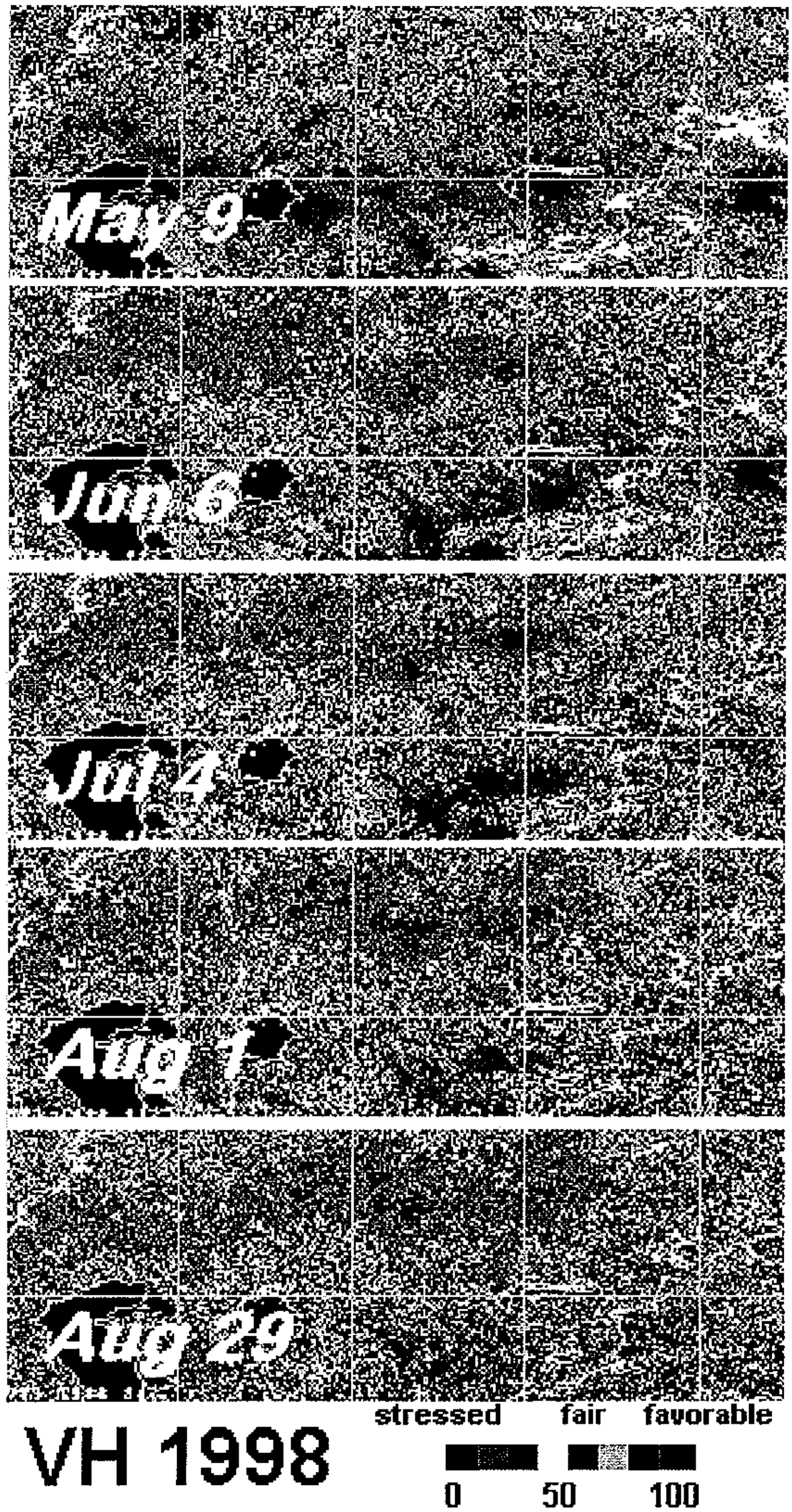


Figure 11. Maps of vegetation health, retrieved from AVHRR data

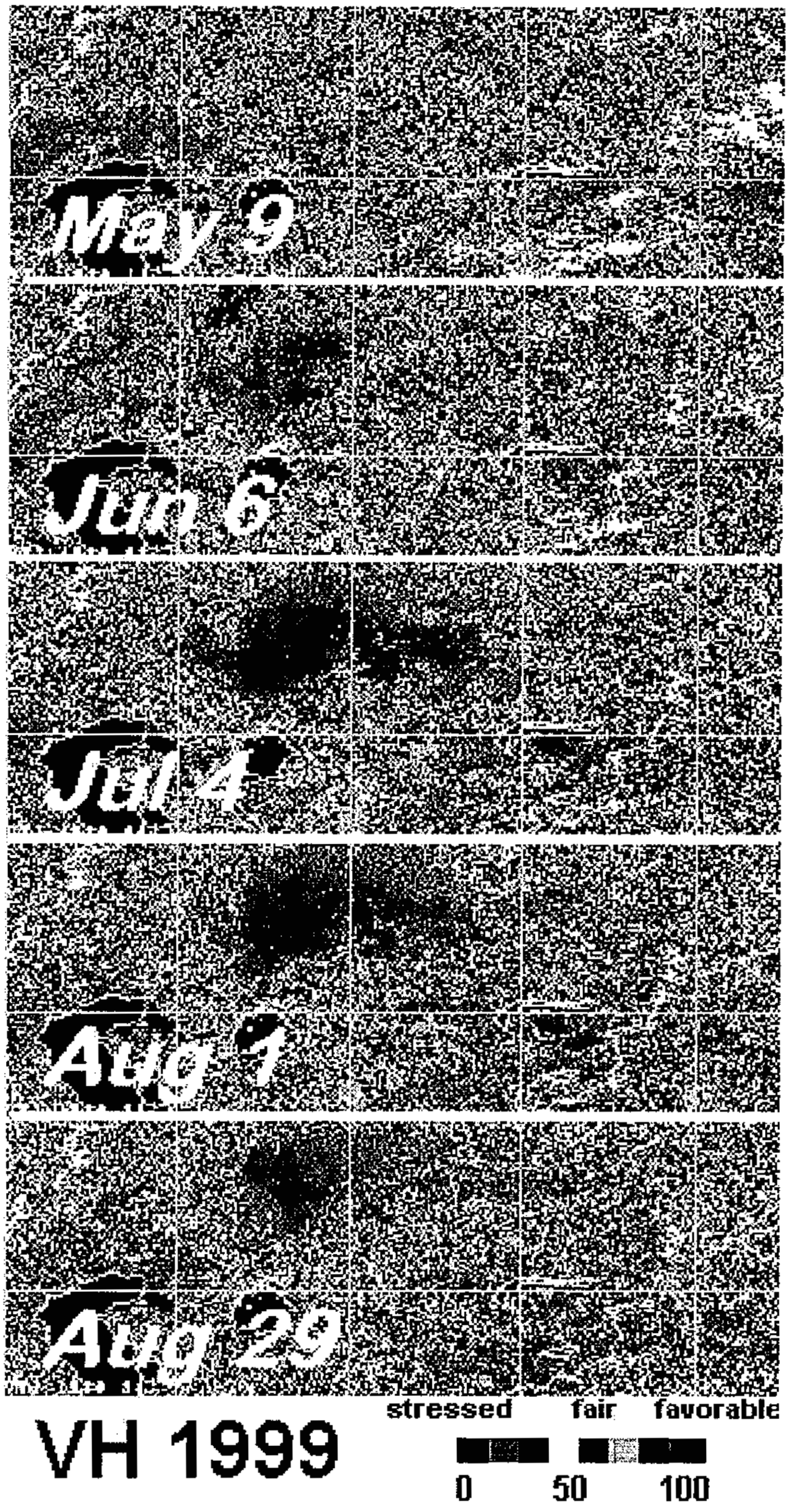


Figure 12. Maps of vegetation health, retrieved from AVHRR data

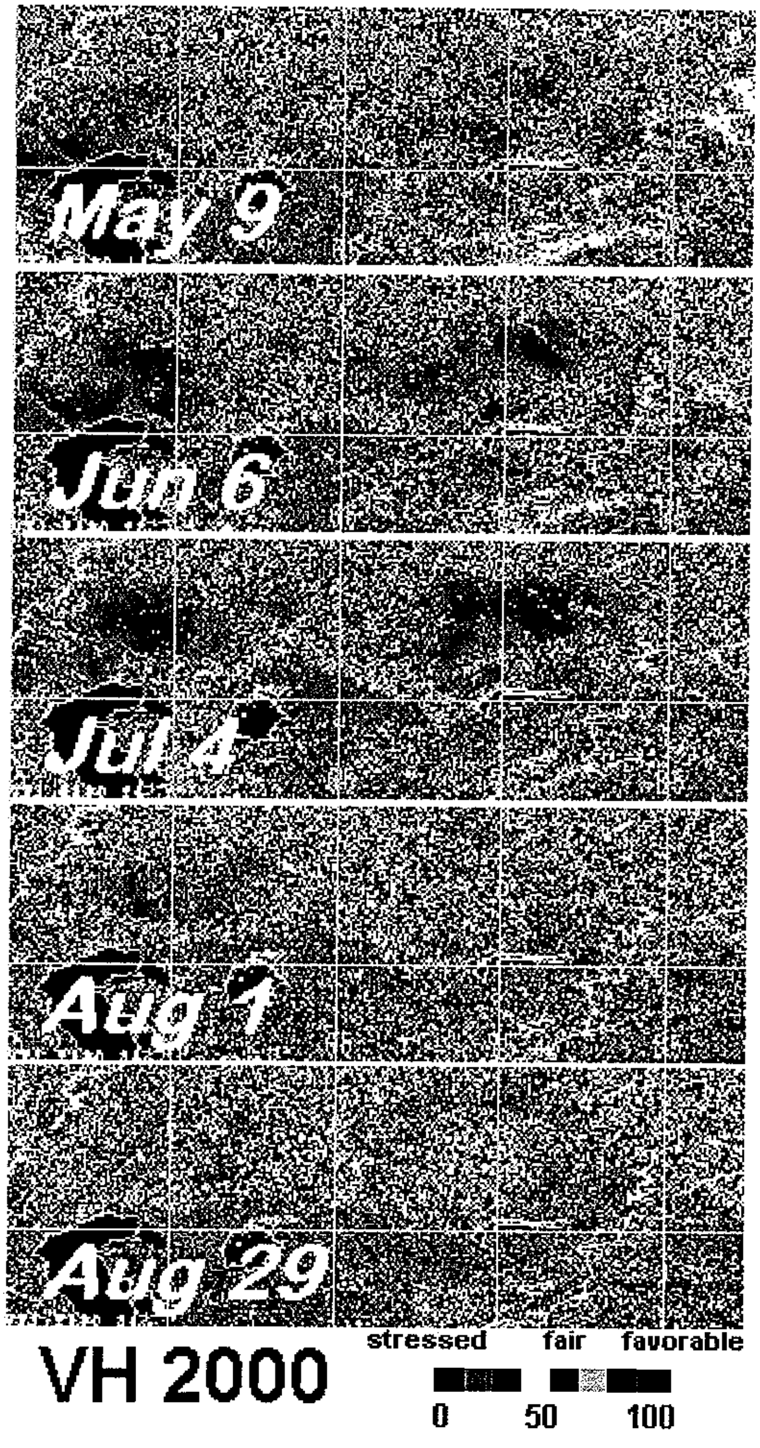


Figure 13. Maps of vegetation health, retrieved from AVHRR data

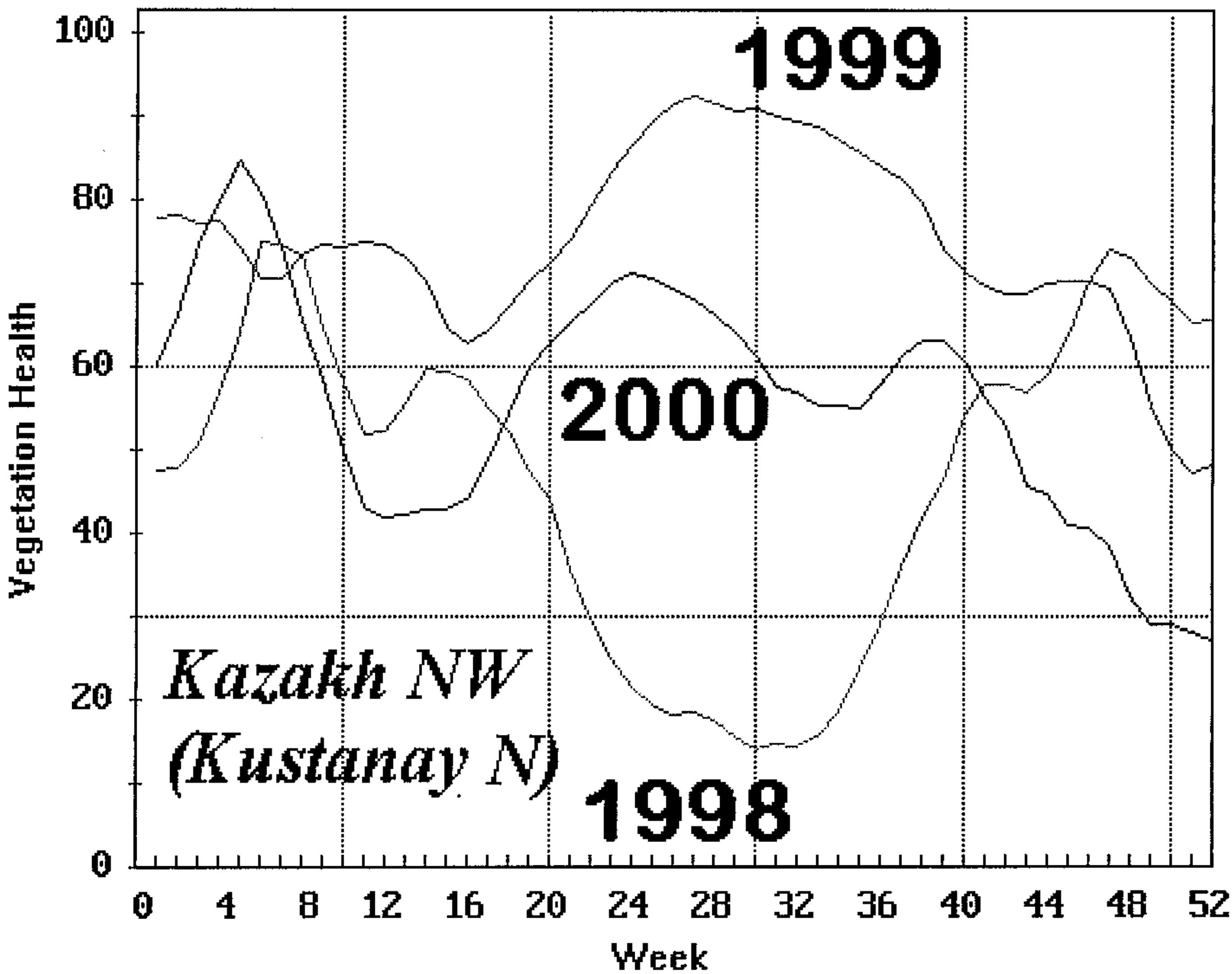


Figure 14. Temporal behavior of vegetation health index retrieved from AVHRR data

5.6. Drought monitoring

Drought is a typical phenomenon in the Kazakhstani climate. Almost all of the Kazakhstan area is located in a zone where annual consumption of water, estimated from potential evapotranspiration, is greater than the annual amount of precipitation (Gol'tsberg, 1972). Kazakhstan experiences both atmospheric and soil droughts; quite often they can be accompanied by a dry wind (dessicative wind). The extreme droughts occur every 5-6 years, while severe and moderate droughts occur once in 3 years and mild droughts occurred almost every year somewhere around the Kazakhstan area. Drought normally affects from 30 to 100 percent of the entire area of Kazakhstan (Kogan, 1985). In the past 100 years, nearly 40 years experienced extreme, severe, or moderate droughts. In the past 10 years above, severe and moderate droughts were observed in 1985, 1989, 1991, 1993 and 1998. The droughts in 1991 and 1993 can be classified as a very severe.

Drought is the most complex but least understood of all natural disasters. Therefore, a universally accepted definition of drought does not exist (Wilhite 1993). The major cause of drought is lack of precipitation. However, the same precipitation deficit may have different impacts depending on other meteorological elements, types of ecosystem, and economic activities. The many definitions of drought reflect these impacts (Wilhite & Glantz, 1985). They might also identify specific climatic conditions, regional differences, physiological characteristics, economic development, and even traditions. Presently, scientific literature classifies drought into four types: meteorological, agricultural, hydrological, and socioeconomic (WMO 1975; Wilhite & Glantz, 1985). Droughts in Kazakhstan belong to the first two types.

Droughts have some specific features that distinguish them from other natural hazards and make them difficult to identify (Wilhite 1993). Drought development is cumulative and builds up slowly over a period of time. The impact of drought on the environment and/or economic activity is also cumulative. Therefore, the losses from drought are not immediately detectable, i.e., there is a lag time. In addition, the absence of a distinctive criterion for drought creates difficulties in identifying drought, assessing its onset, duration, aerial extent, and severity. Drought spreads over a large area, making it difficult to identify its impact. In sum, drought is not easily identifiable, especially at the very beginning, even if the appropriate weather observations are available.

Lack of biophysical drought criteria and difficulties in estimating drought impact on vegetation and the environment make vegetation indices, especially VCI, very attractive as tools for drought detection and monitoring. In recent years, the VCI has found applications for drought monitoring in areas with very different ecological and economic resources (Kogan, 1994, 1995a).

Figures 15-17 show the result of VCI application for drought monitoring in 1998 for the entire area of Kazakhstan.

This system constitutes the principal part of a crop and pasture early warning system. The findings of the project have helped to increase the accuracy of agricultural production estimates, the spatial distribution of production, and the timeliness of delivery of these estimates to customers.

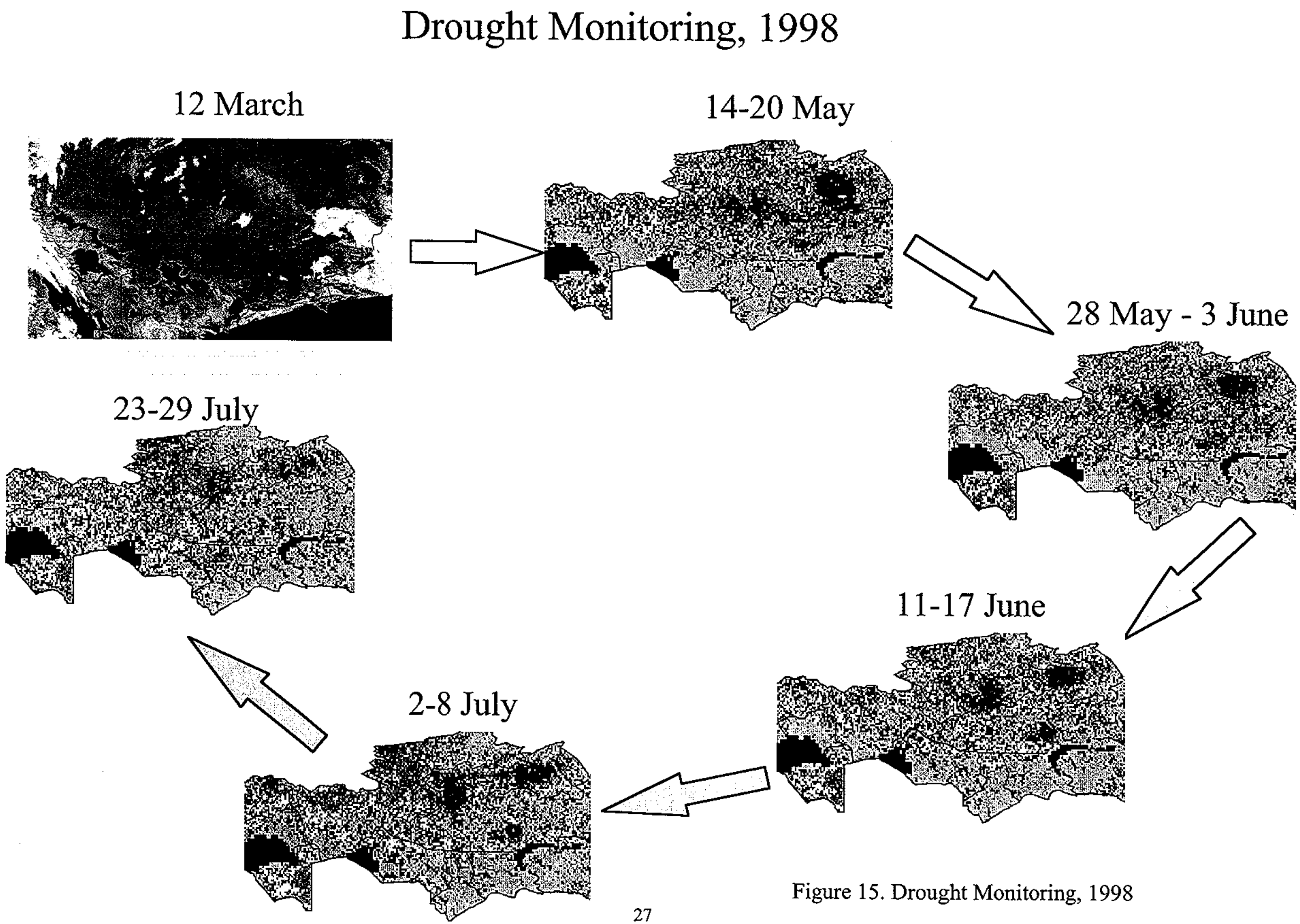
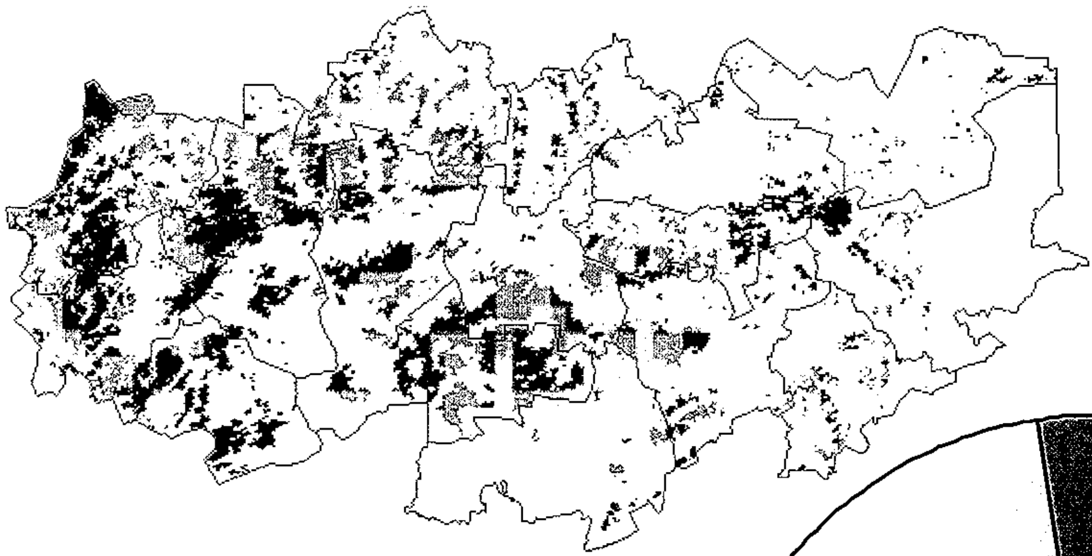


Figure 15. Drought Monitoring, 1998

Akmola Region



Conditions of crop

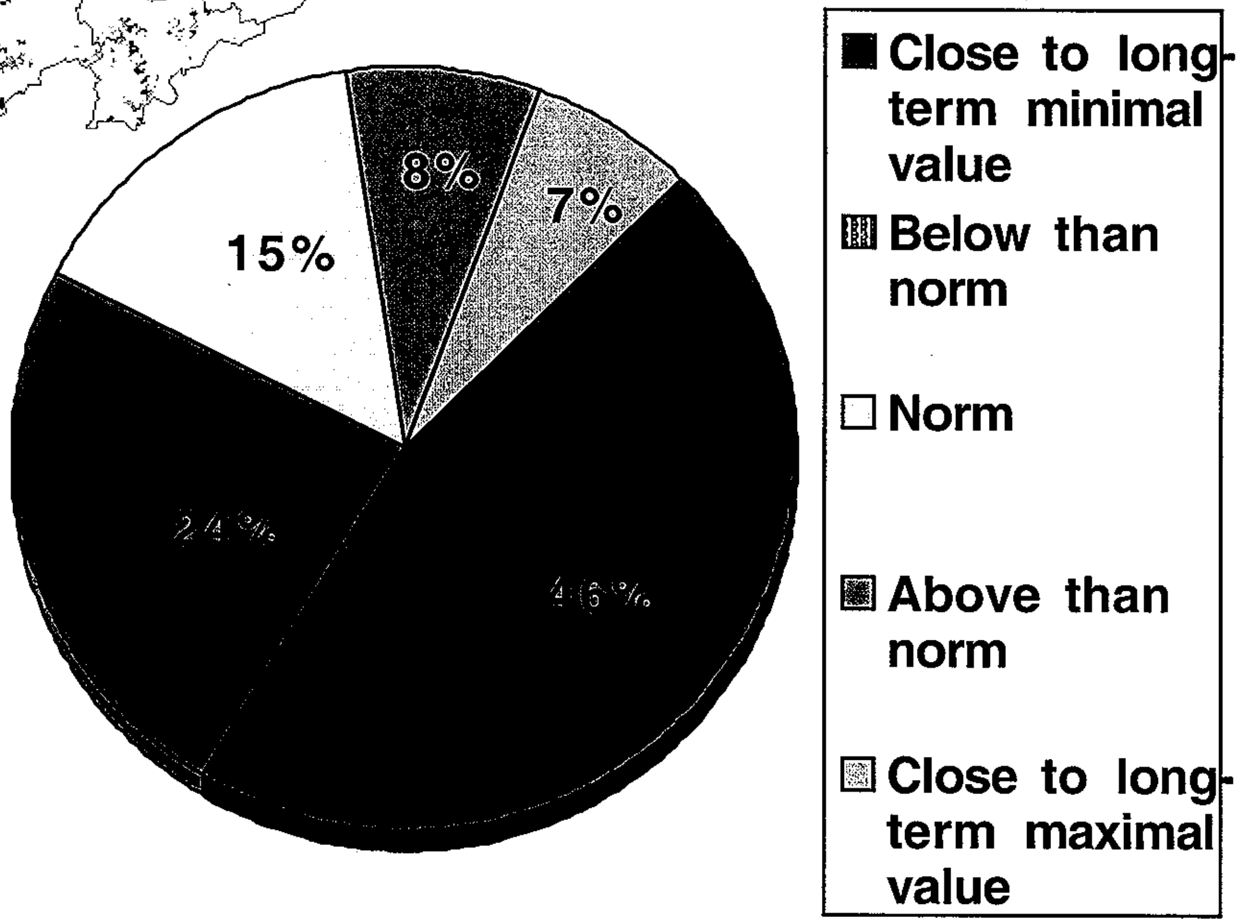
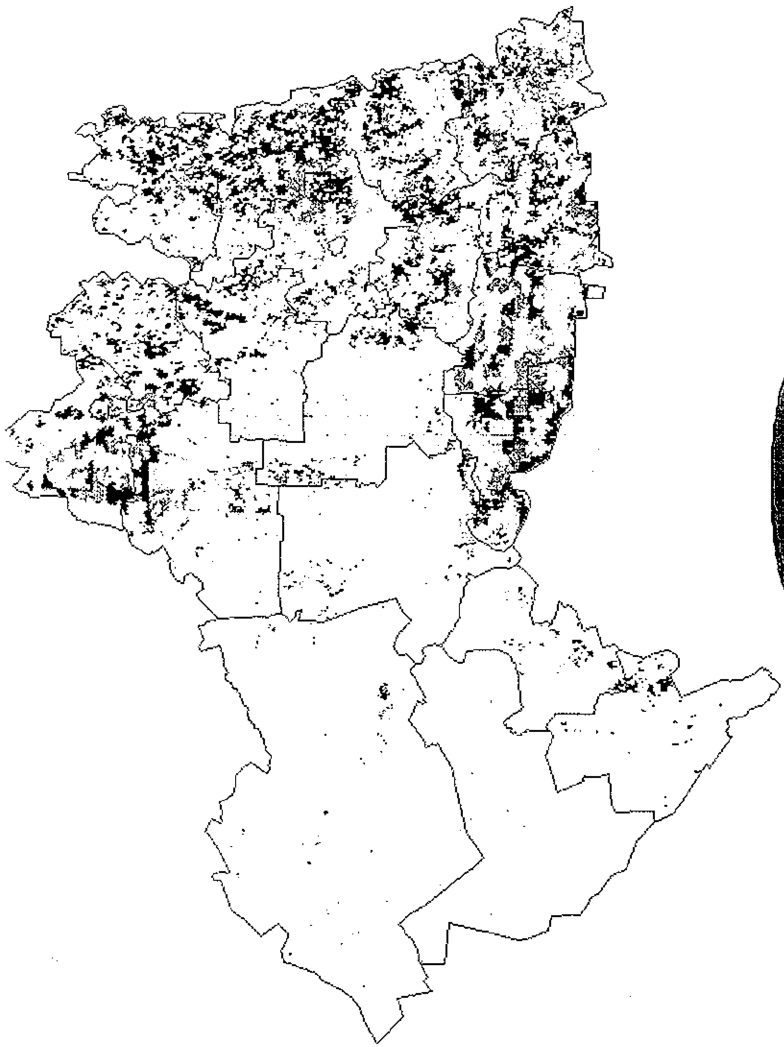


Figure 16. Crop Conditions during 1998, retrieved from AVHRR data

Kostanay Region



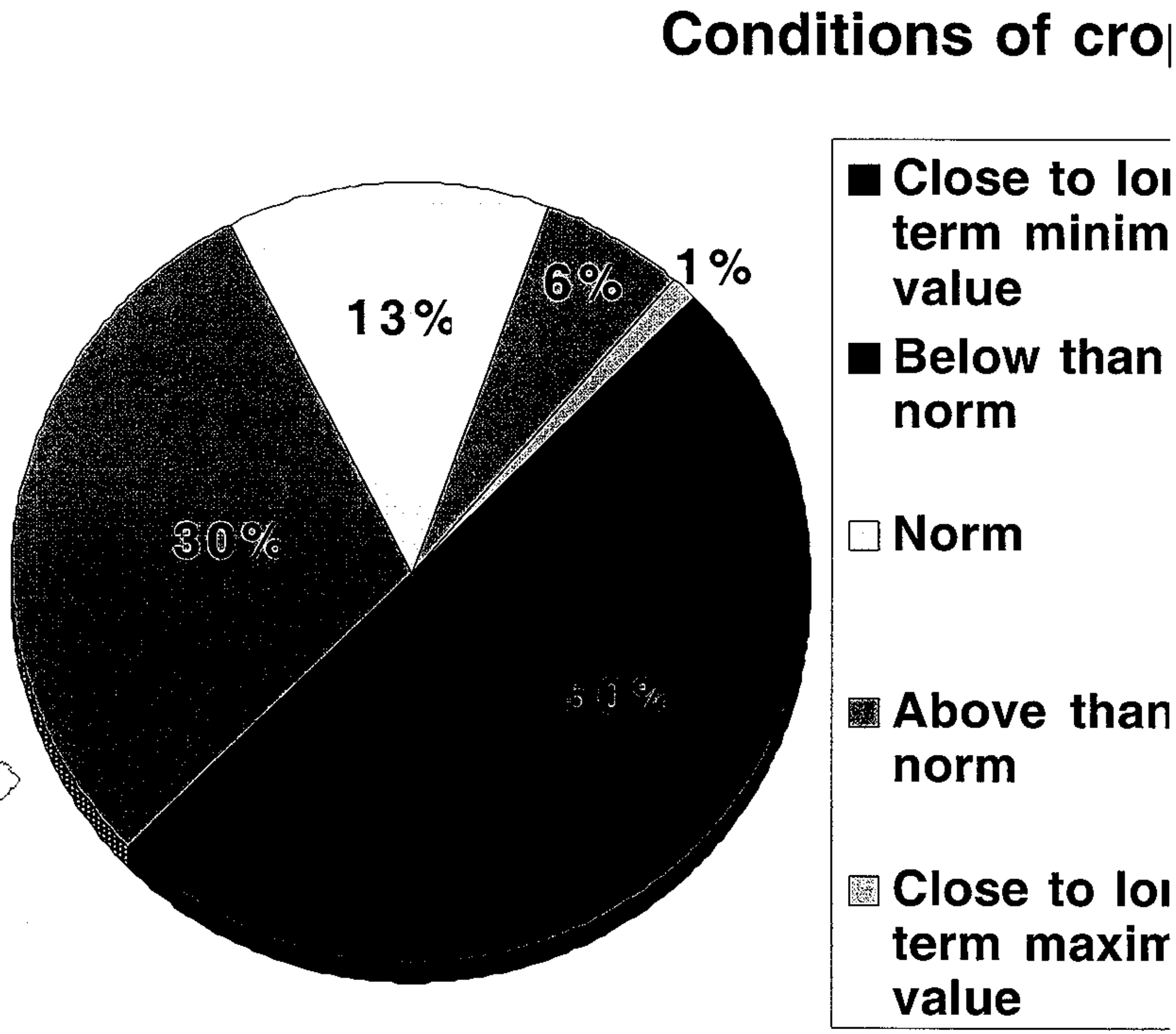


Figure 17. Crop Conditions during 1998, retrieved from AVHRR data

5.8 Operational monitoring of sowing areas, snow cover and temperature.

Important application of space data was operational monitoring of sowing areas. Results of NDVI calibration versus cereal yield showed in Fig. 18. AVHRR-retrieved maps of sowing areas and yield prediction in several climatic zones of Kazakhstan shown in Fig. 18 and 19.

Snow cover is an important factor in prediction of soil moisture. It is also widely in use in climatic model. Monitoring of snow cover is operational in Kazakhstan. Figures 20-26 show snow cover dynamic monitored in 2001. The maps were used in Kazakhstan by decision makers and in academic institutions.

Monitoring of surface temperature was introduced in Kazakhstan in 1999. Figures 27-30 are examples of such monitoring.

Figures 31-57 show operational products of 1998 annual monitoring of Kazakhstan environments, including vegetation fraction and status, snow cover, and sowing areas.

5.9 Estimation of desertification processes in Kazakhstan

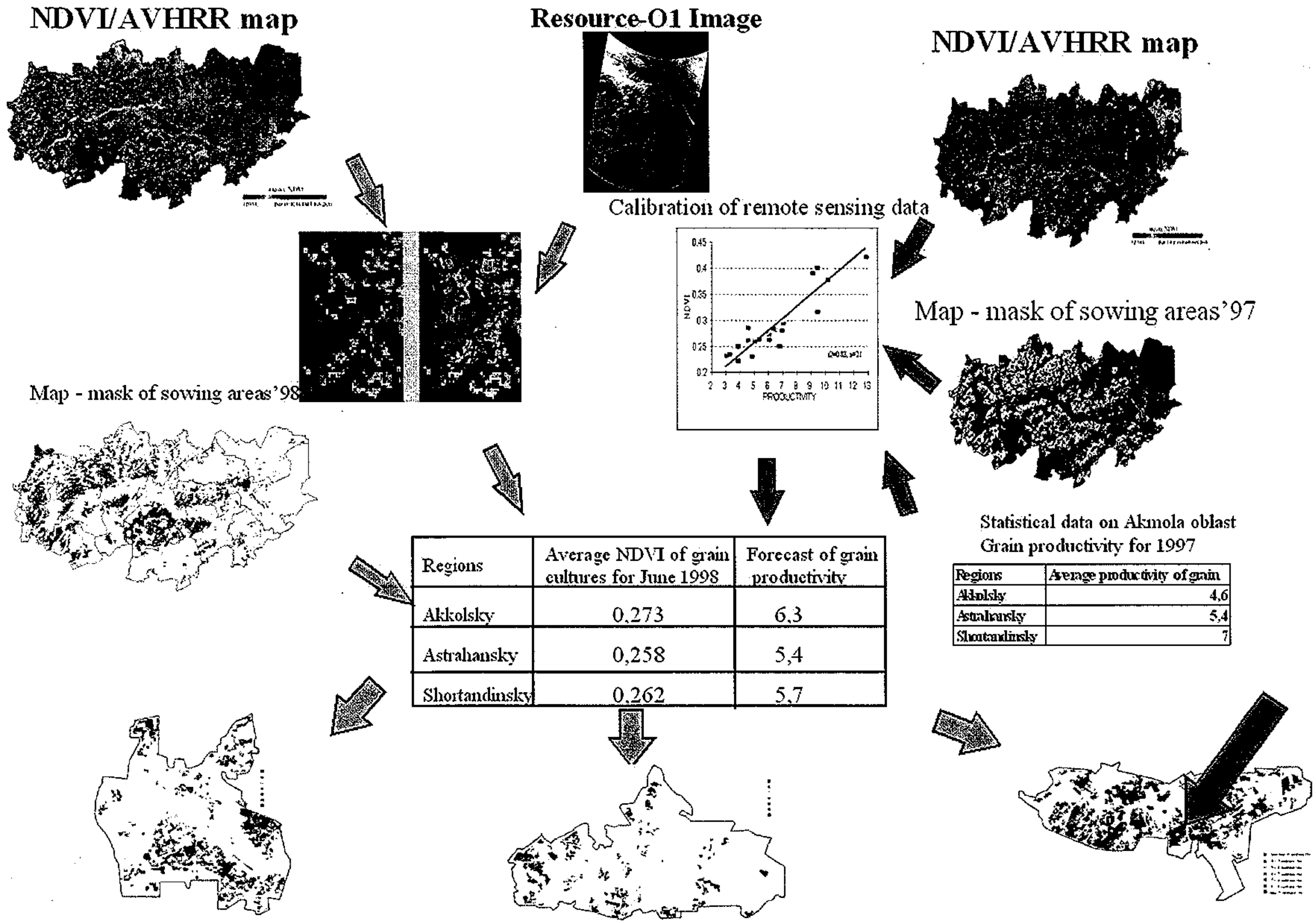
To estimate whether desertification processes in Kazakhstan take place during the last decade, the Kazakh team suggested using AVHRR/NOAA archive of satellite data since1985 (Terehov et al., 2000). They carried out comparison of average and mean VCI values for a period of five years, beginning from 1986 to 1990. Thus, eight maps of VCI were developed: 1986-1990; 1987-1991; 1988-1992; 1989-1993; 1990-1994; 1991-1995; 1992-1996; 1993-1997 (Figs. 58-60).

The results show dynamics of vegetation status for each pixel of Kazakh territory. In the mid-nineties, vegetation state improved significantly comparable to that of 1985 to 1990. Few regions are exceptions. This finding requires special consideration. The results are opposite to the widely held belief that there are strong desertification processes in Kazakhstan. Terehov et al., (2000a) suggest considering another very important factor that could contribute to the increase in vegetation conditions in the nineties: the sharp decrease of anthropogenic impact, beginning with the collapse of the former Soviet Union.

5.10 Technique for estimation of agricultural lands productivity using AVHRR data

Terechov et al., (2000b) suggested a technique for estimation of productivity of Kazakh agricultural lands. They considered lands with maximal NDVI values during growing season (22 weeks) exceeded 0.24 (Fig. 61A). To locate "stable" agricultural zones, they suggested using the difference between $NDVI_{max}$ and $NDVI_{min}$ values for each pixel. The less this difference, the less productivity variation in most favorable and less favorable whether conditions. Thus, the less the difference, the more stable is the agricultural zone. Fig. 61B shows a map of "stability" of agricultural lands with respect to their productivity. Kazakh team and Institutions in Kazakhstan who used this information, claim that the maps produced using satellite data, are extremely important for Republic; it is very helpful in strategic planning for specific Kazakh regions development as well as in rational land use.

Estimation of Cereal Yield



Regions	Average NDVI of grain cultures for June 1998	Forecast of grain productivity
Akkolsky	0,273	6,3
Astrahansky	0,258	5,4
Shortandinsky	0,262	5,7

Statistical data on Akmola oblast
Grain productivity for 1997

Regions	Average productivity of grain
Akkolsky	4,6
Astrahansky	5,4
Shortandinsky	7

Figure 18. AVHRR retrieved estimation of sowing areas and yield prediction

Cereal Yield

Shortandinsky region of Akmola region

Figure 19. AVHRR retrieved yield prediction

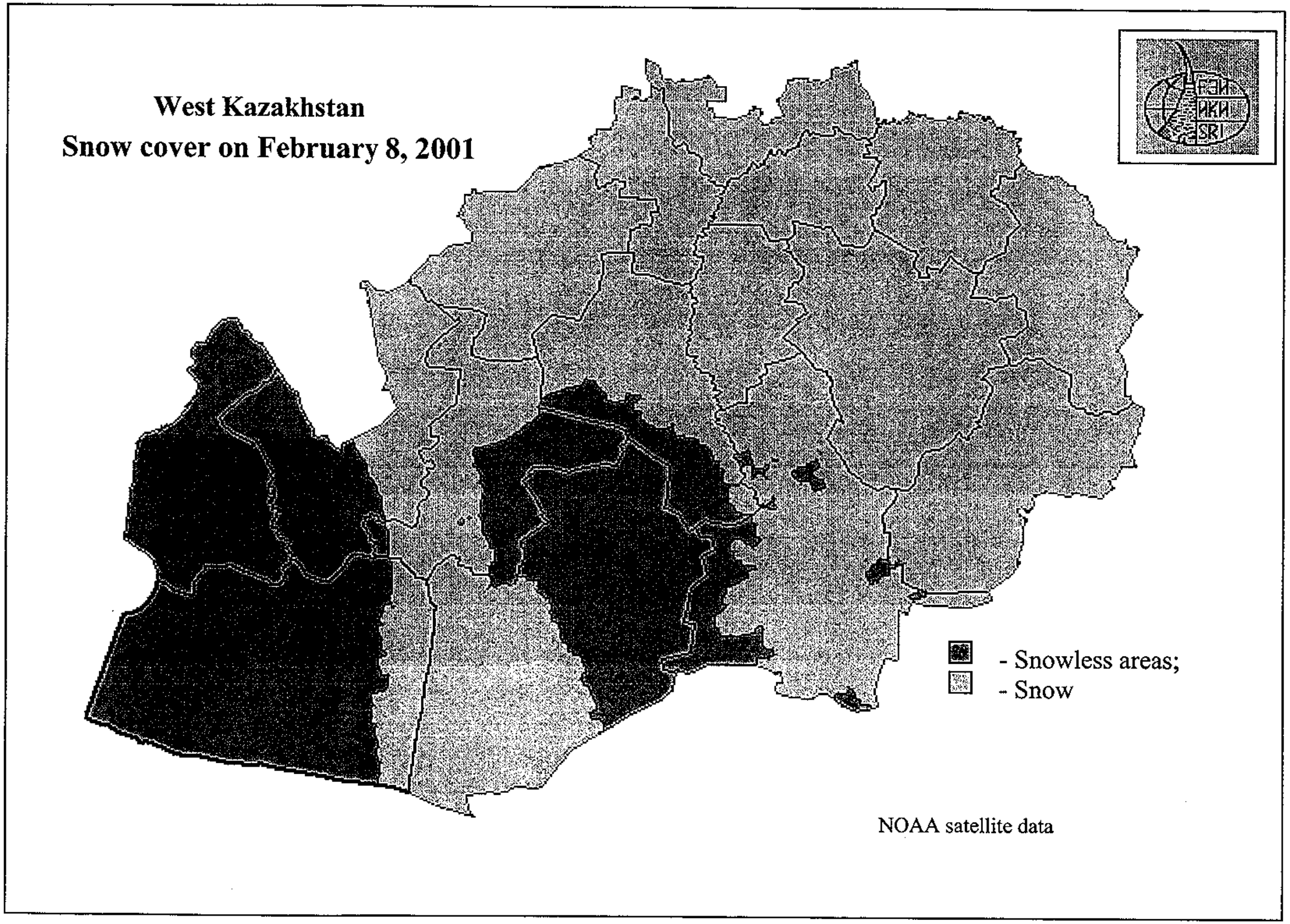


Figure 20. Snow cover on February 8, 2001

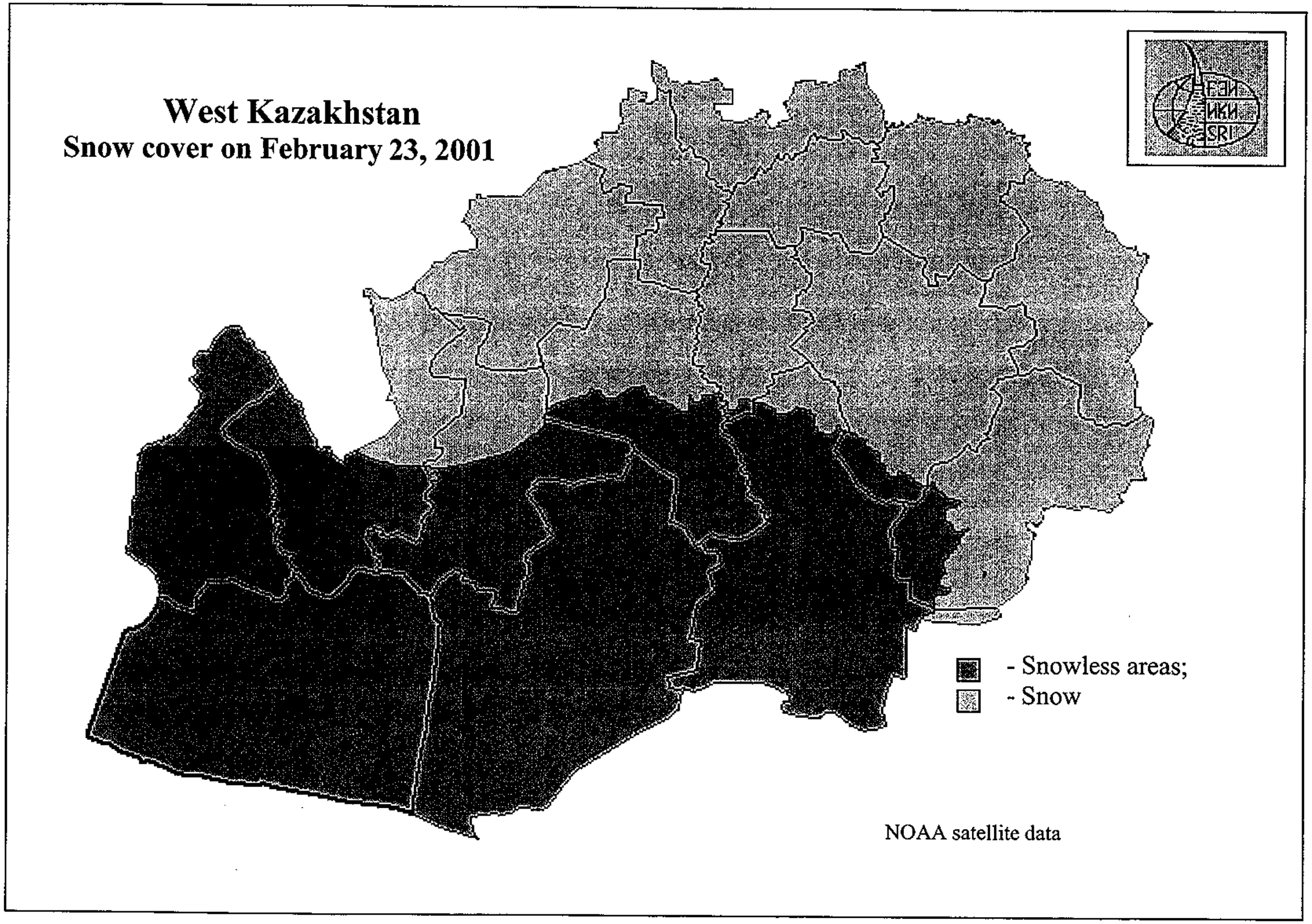


Figure 21. Snow cover on February 23, 2001

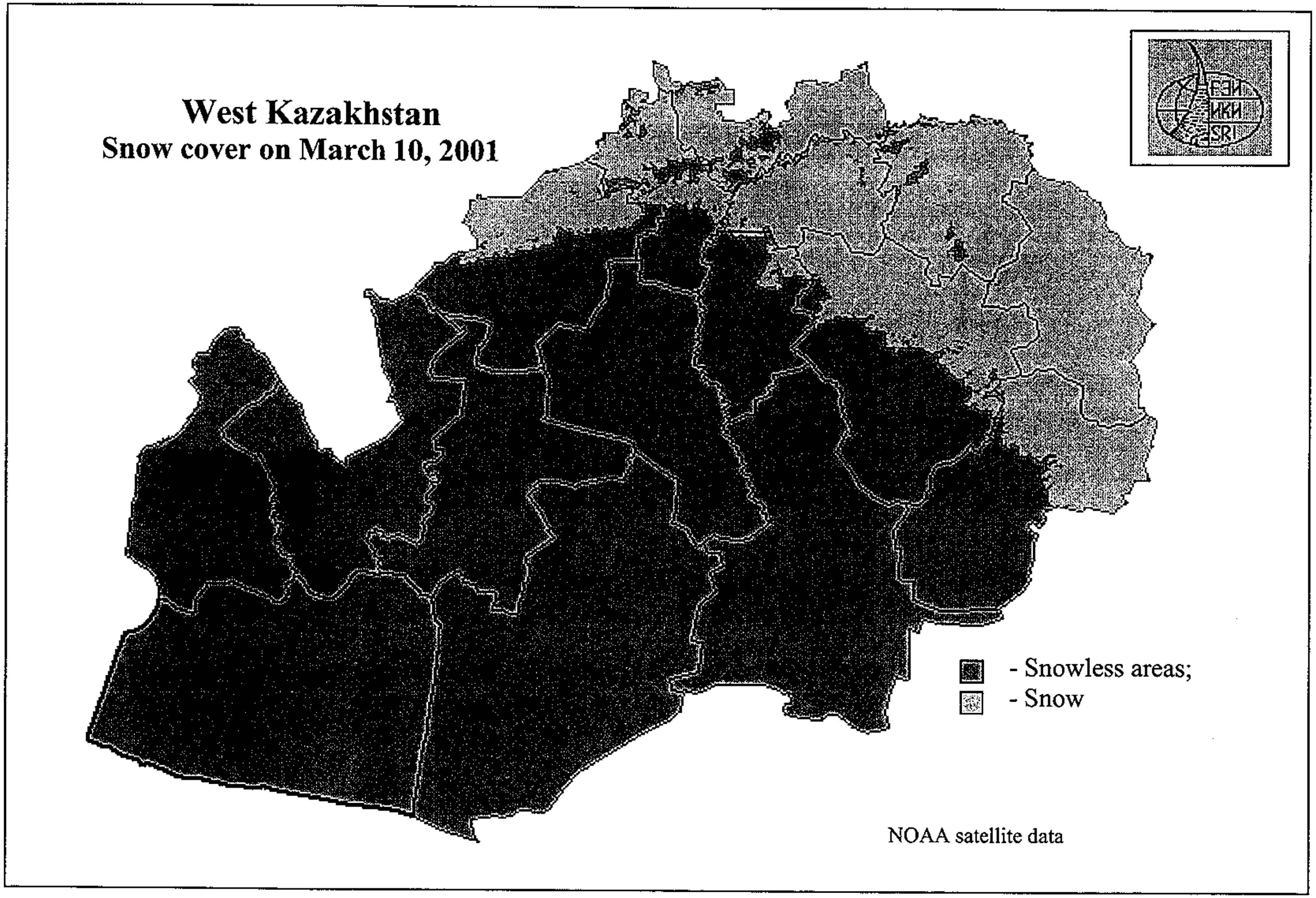


Figure 22. Snow cover on March 10, 2001

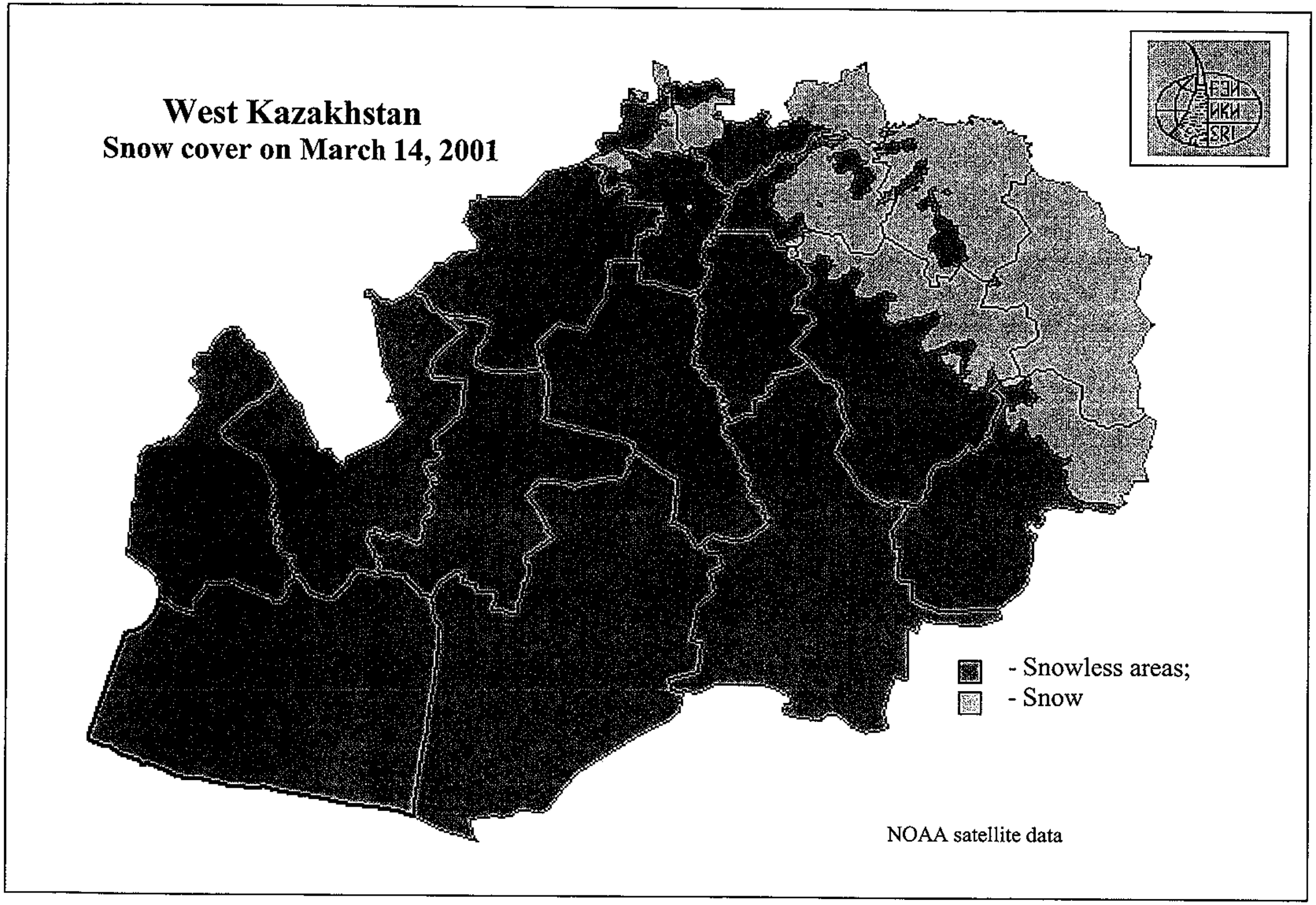


Figure 23. Snow cover on March 14, 2001

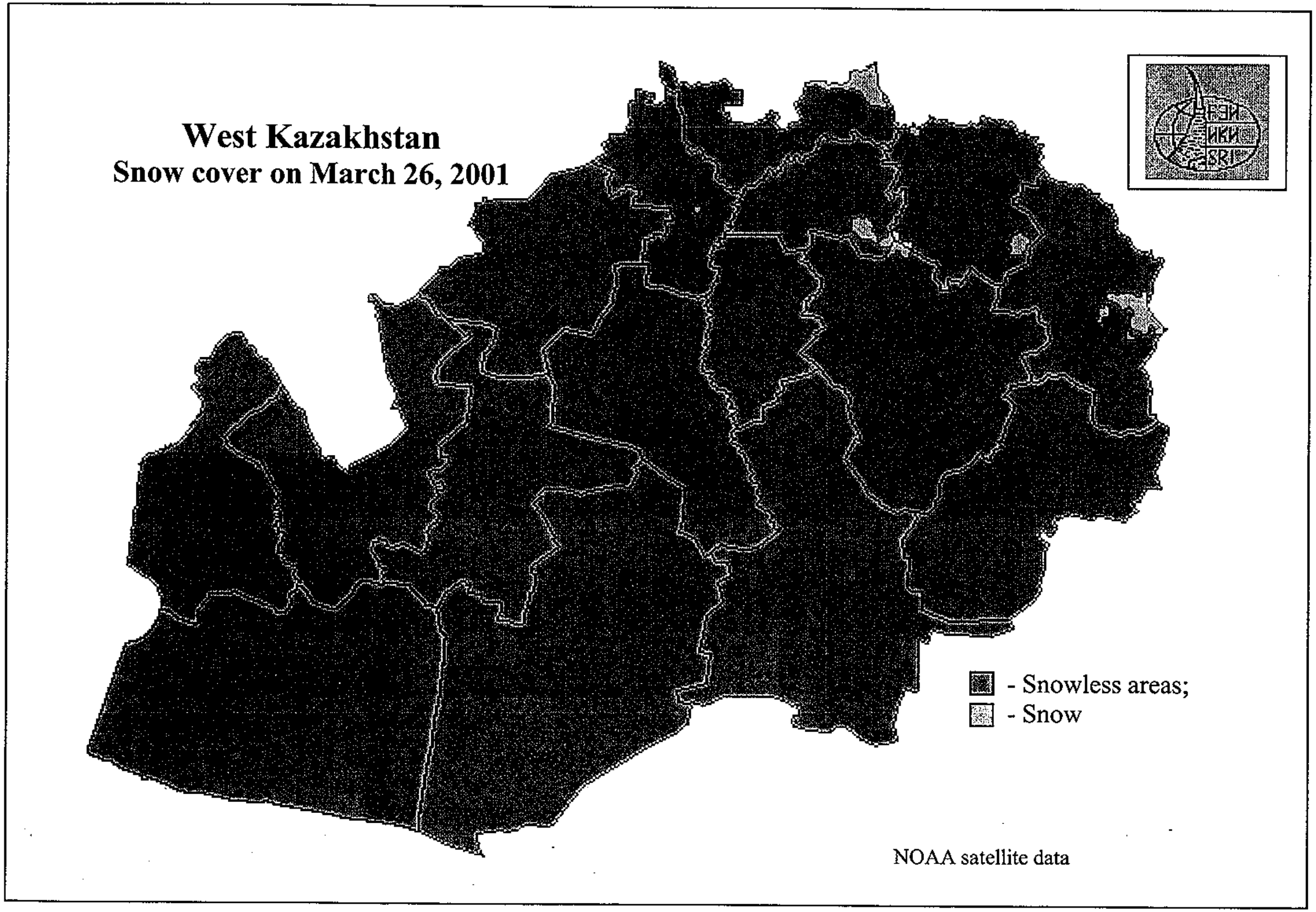


Figure 24. Snow cover on March 26, 2001

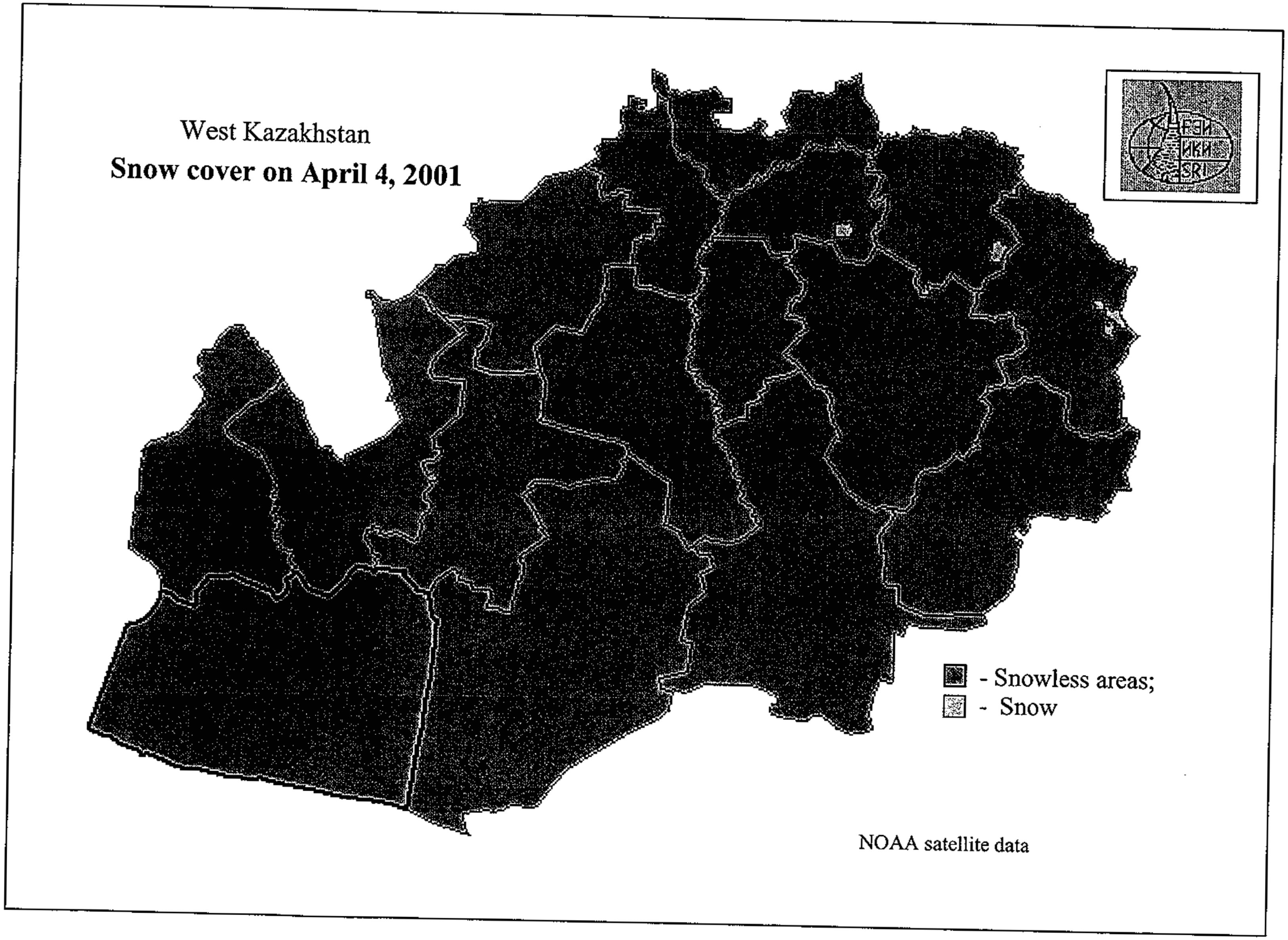


Figure 25. Snow cover on April 4, 2001

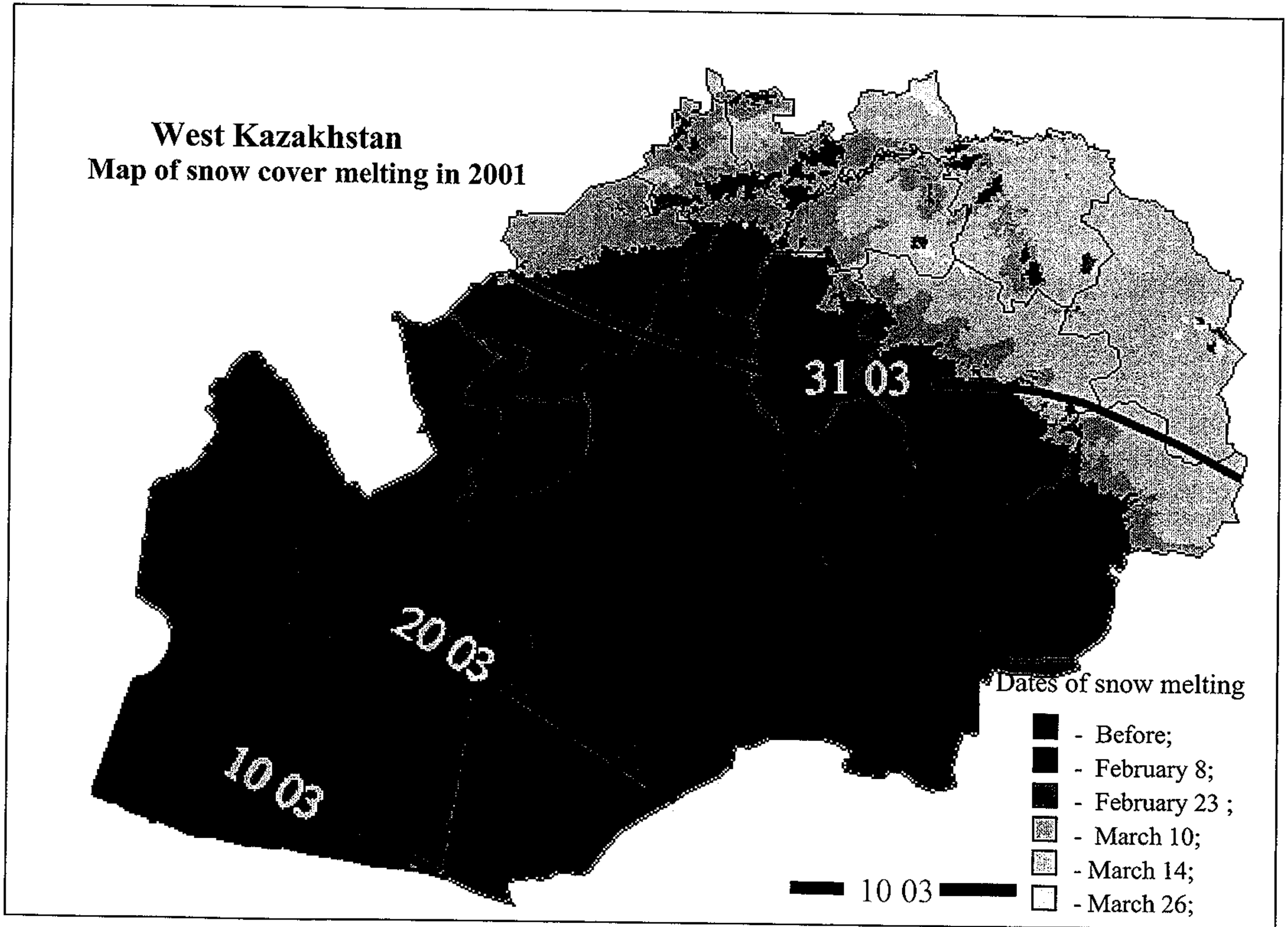


Figure 26. Map of snow cover / melting in 2001

TEMPERATURE MAP OF WEST KAZAKHSTAN

March 10, 2001

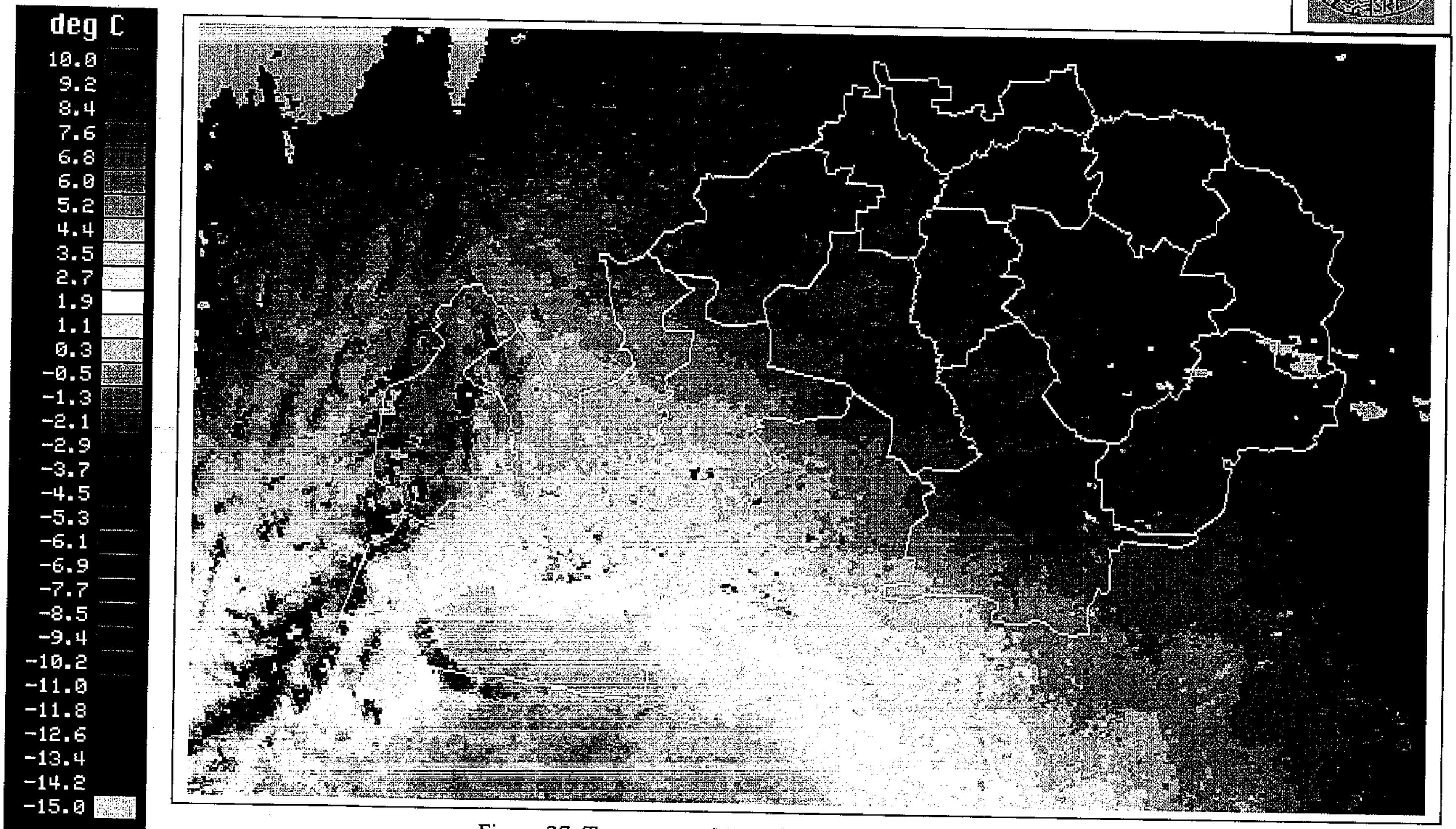


Figure 27. Temperature Map of West Kazakhstan, March 10, 2001

TEMPERATURE MAP OF WEST KAZAKHSTAN

March 26, 2001

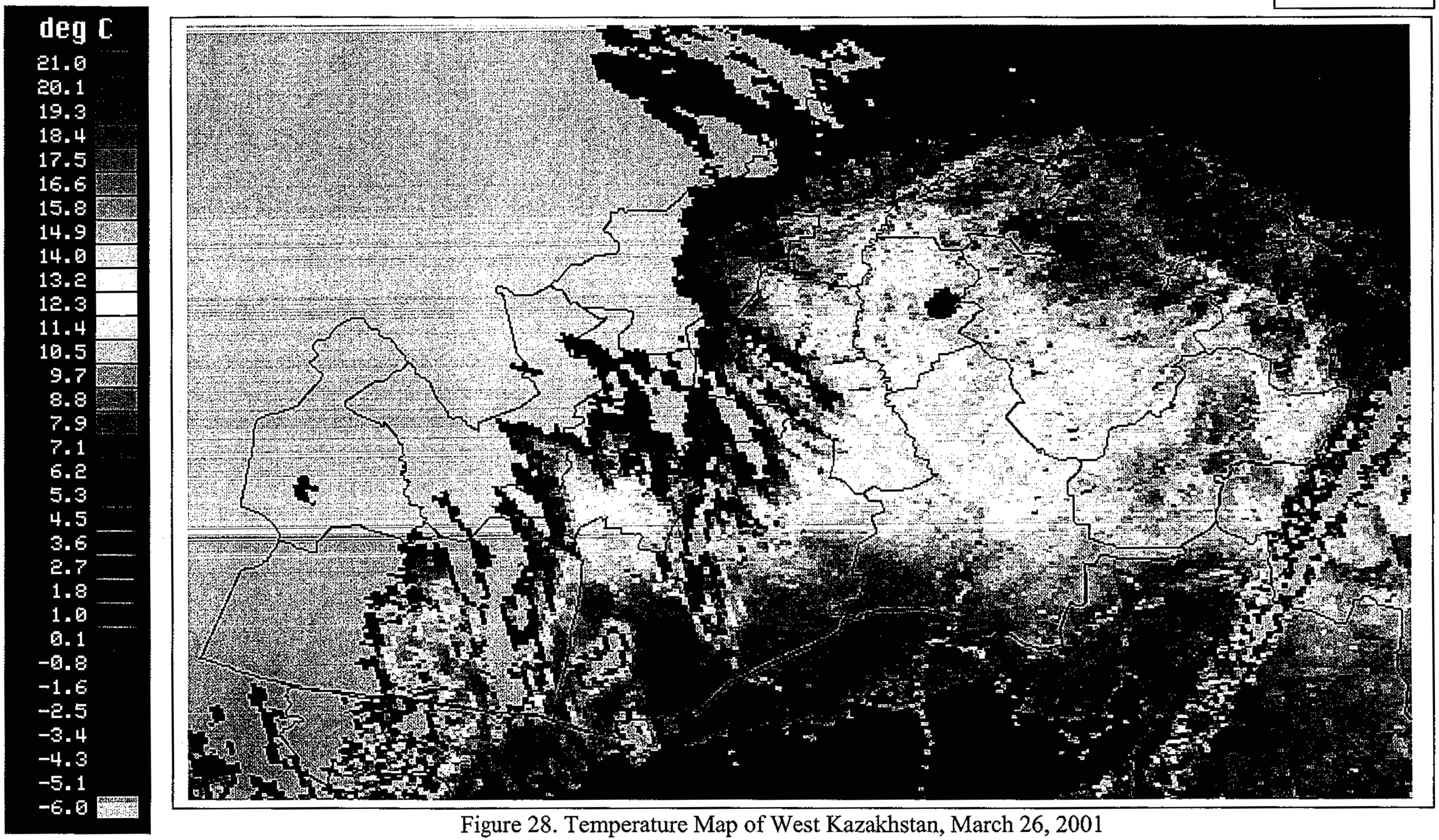


Figure 28. Temperature Map of West Kazakhstan, March 26, 2001

TEMPERATURE MAP OF WEST KAZAKHSTAN

April 1, 2001

Figure 29. Temperature Map of West Kazakhstan, April 1, 2001

TEMPERATURE MAP OF WEST KAZAKHSTAN OBLACT

April 11 – 15, 2001

Figure 30. Temperature Map of West Kazakhstan, April 11-15, 2001

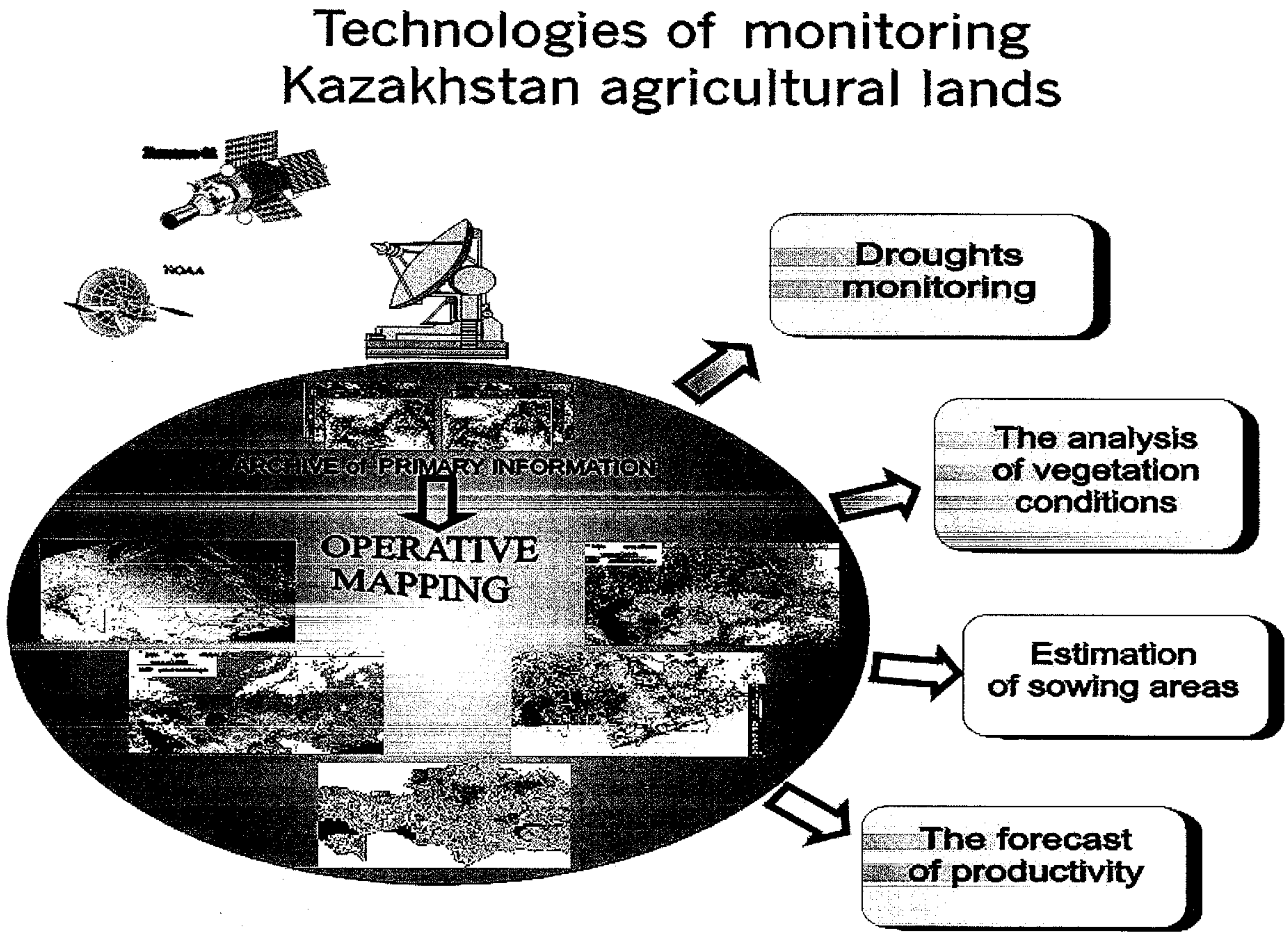


Figure 31. Technologies of monitoring Kazakhstan agricultural lands

Annual monitoring

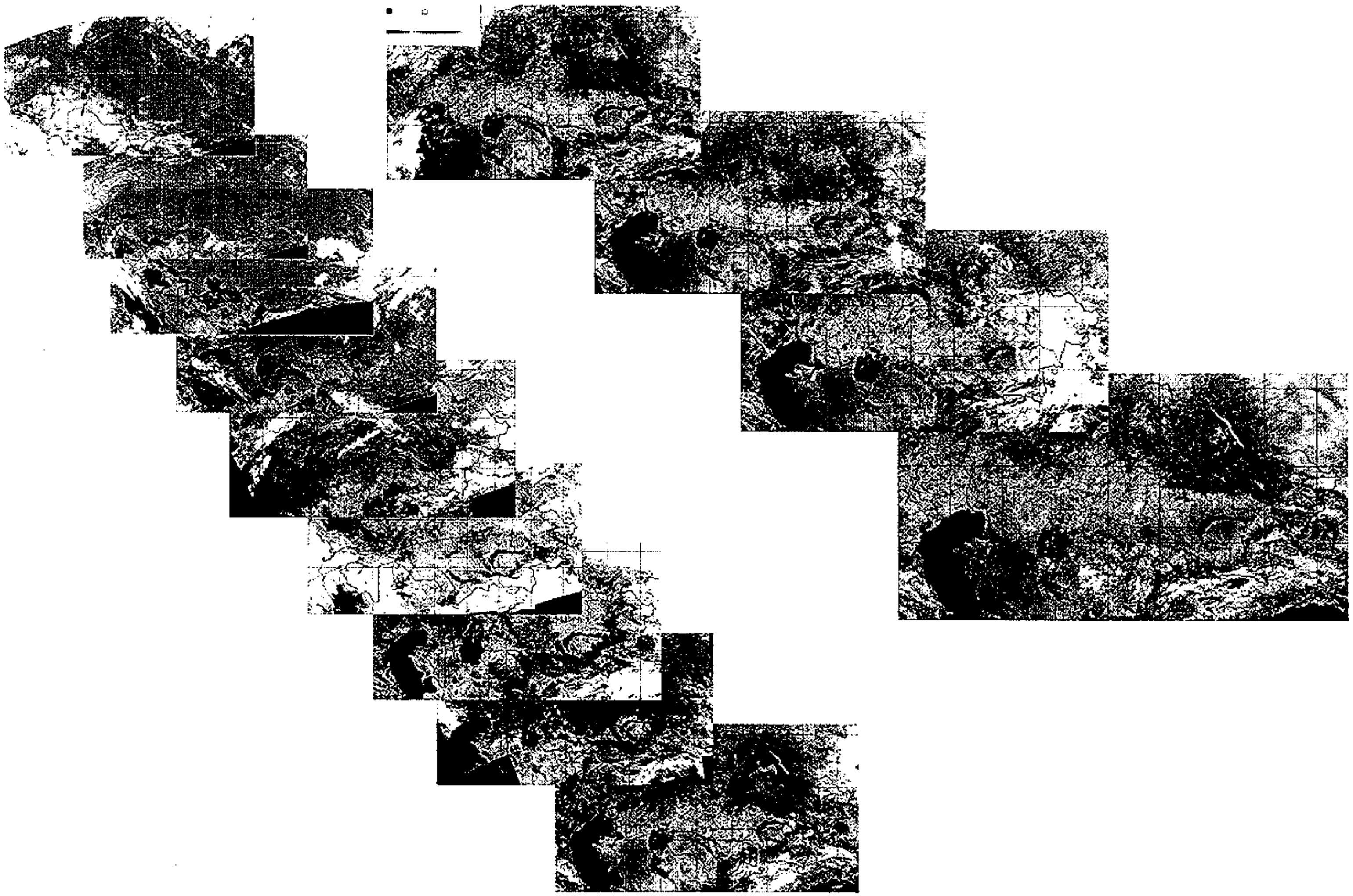


Figure 32. Annual Monitoring

Annual monitoring

21 January 1998

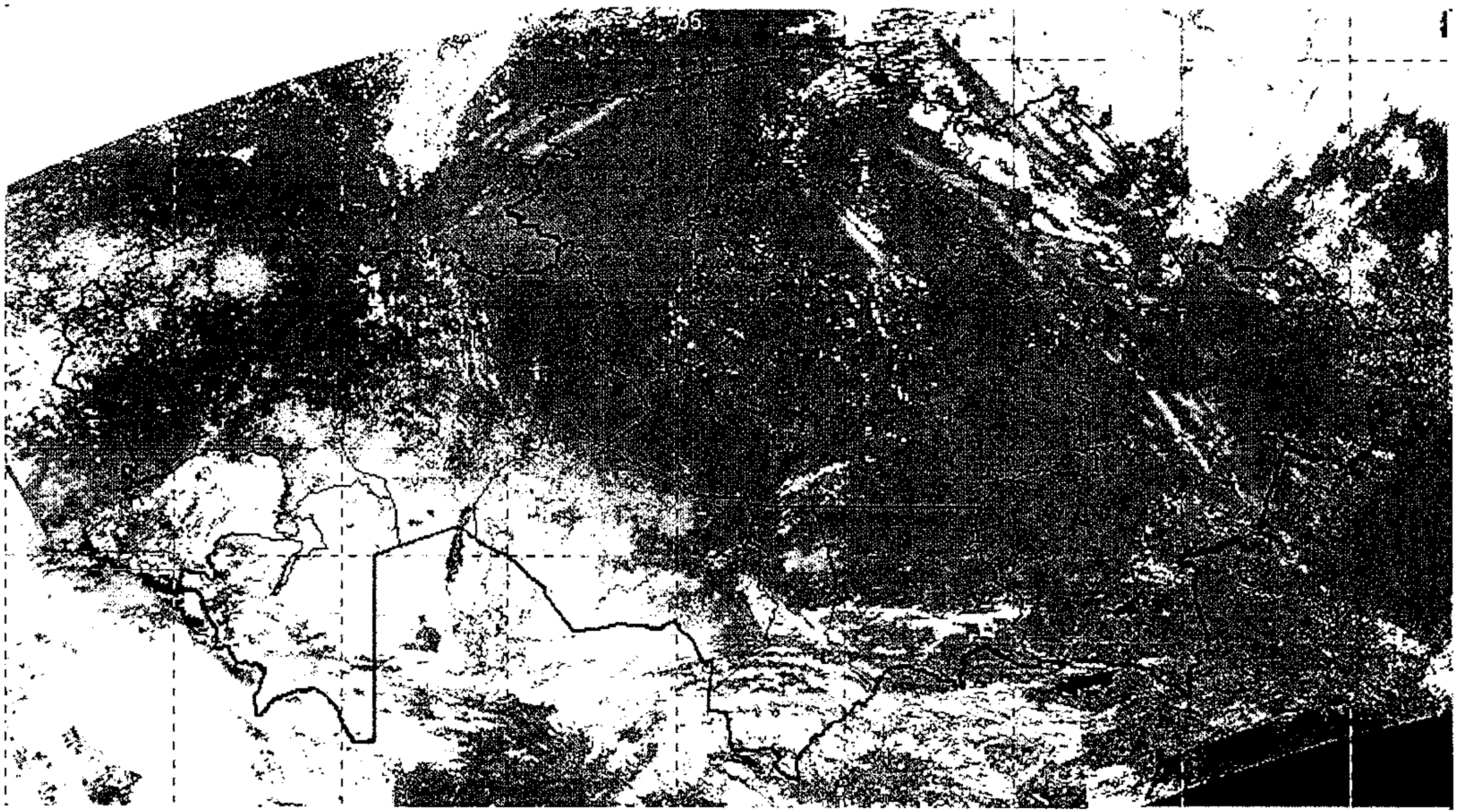


Figure 33. Annual Monitoring

Annual monitoring

25 February 1998

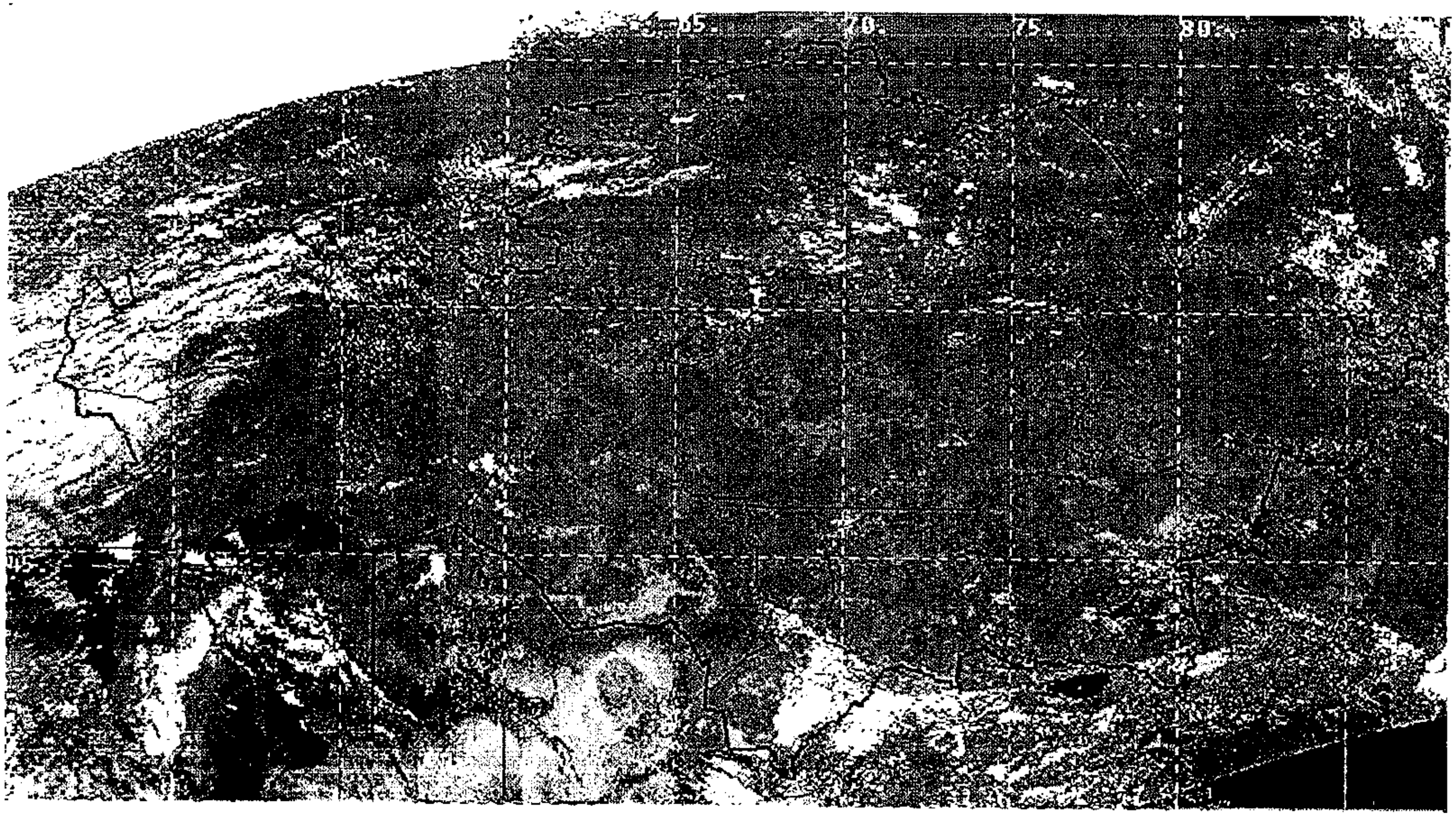


Figure 34. Annual Monitoring

Annual monitoring

12 March 1998

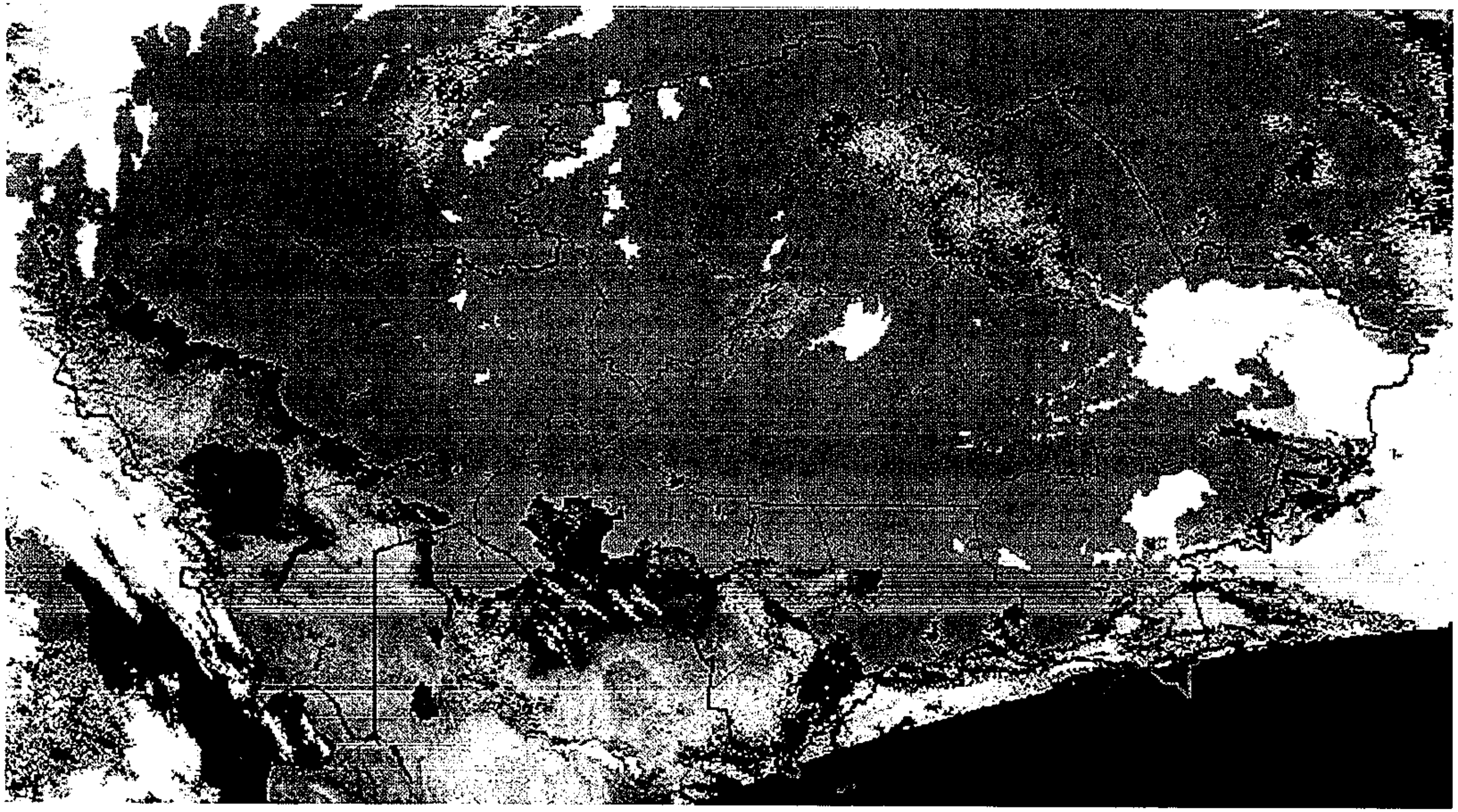


Figure 35. Annual Monitoring

Annual monitoring

5 April 1998

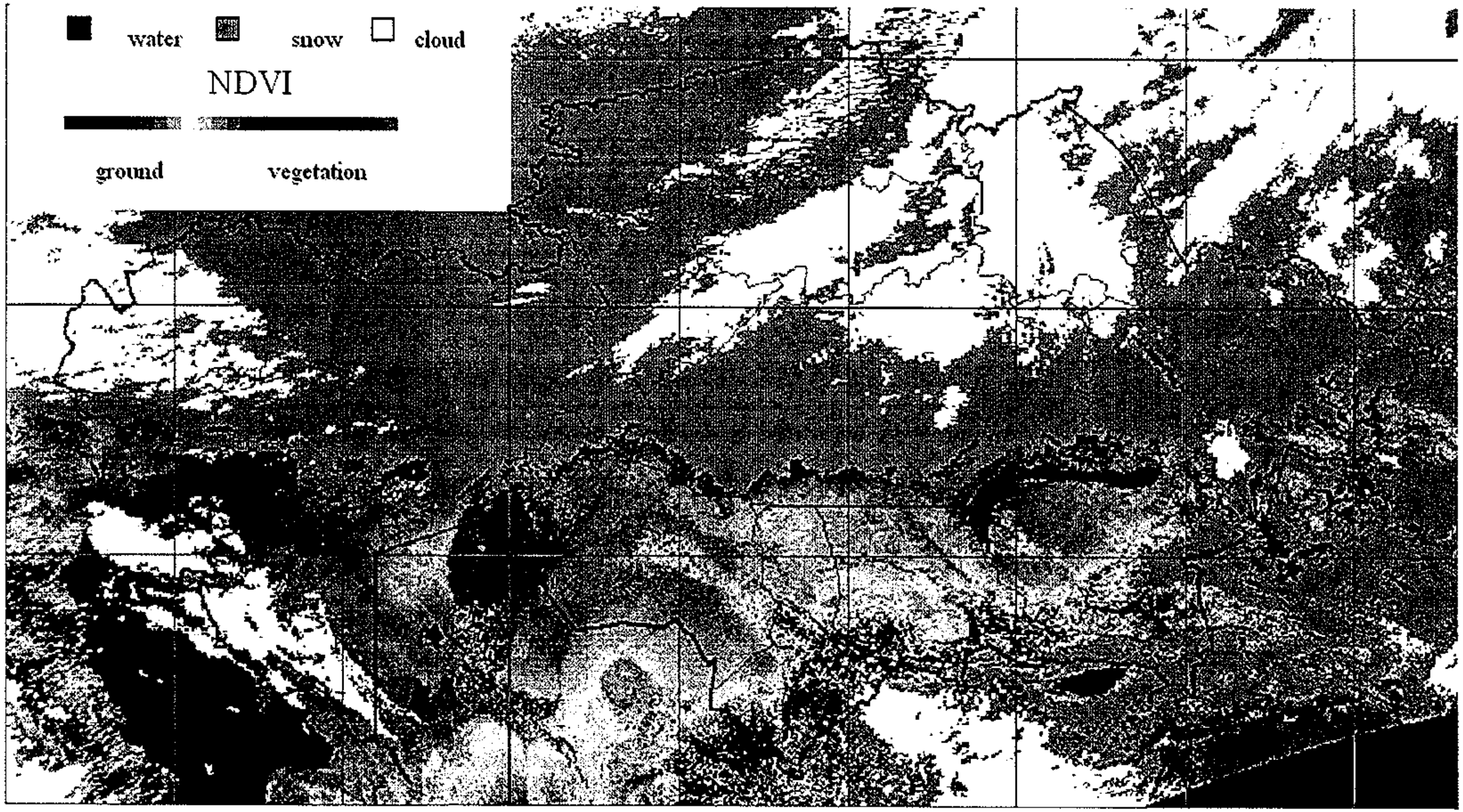


Figure 36. Annual Monitoring

Annual monitoring

14 April 1998

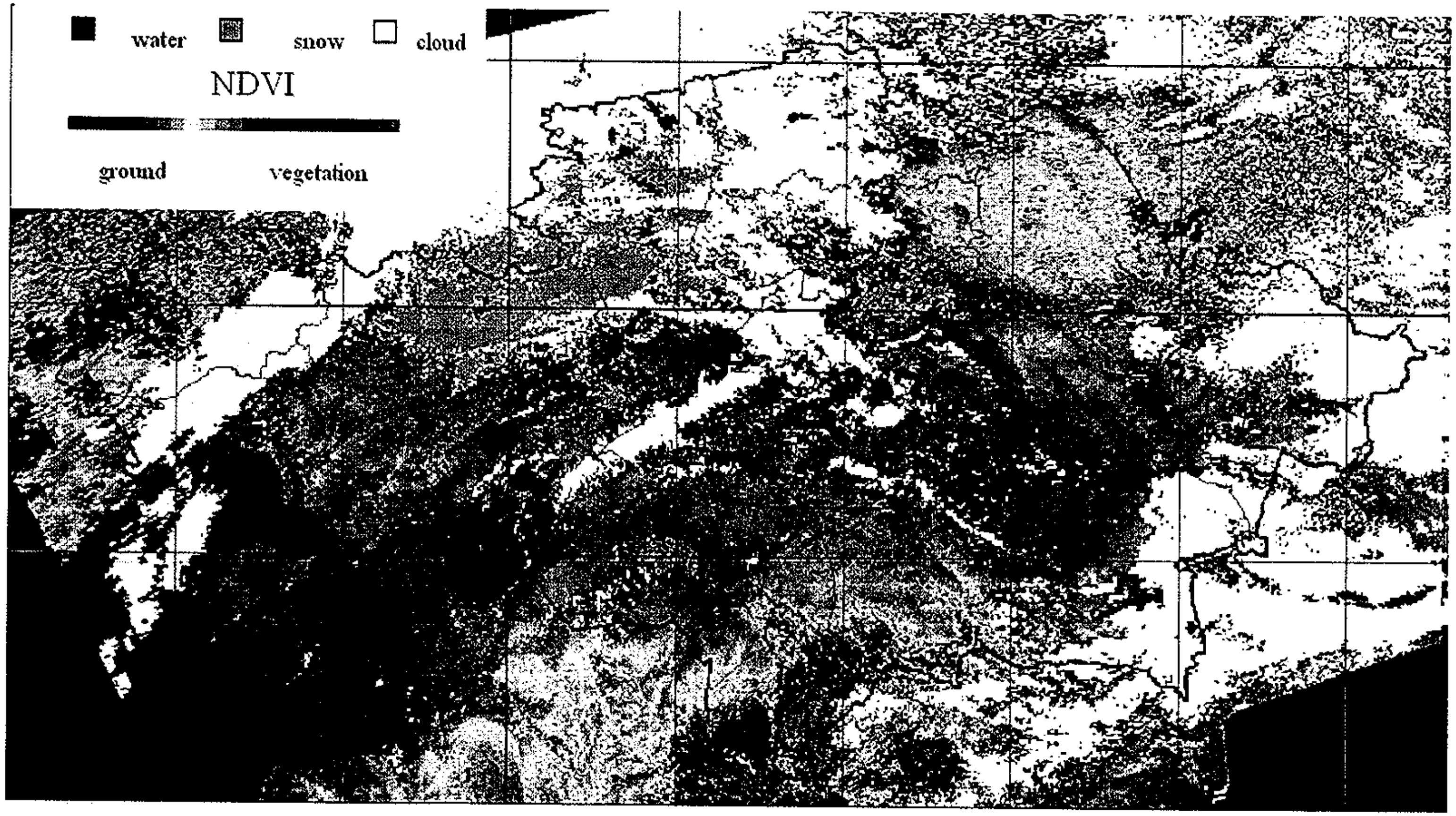


Figure 37. Annual Monitoring

Annual monitoring

21 April 1998

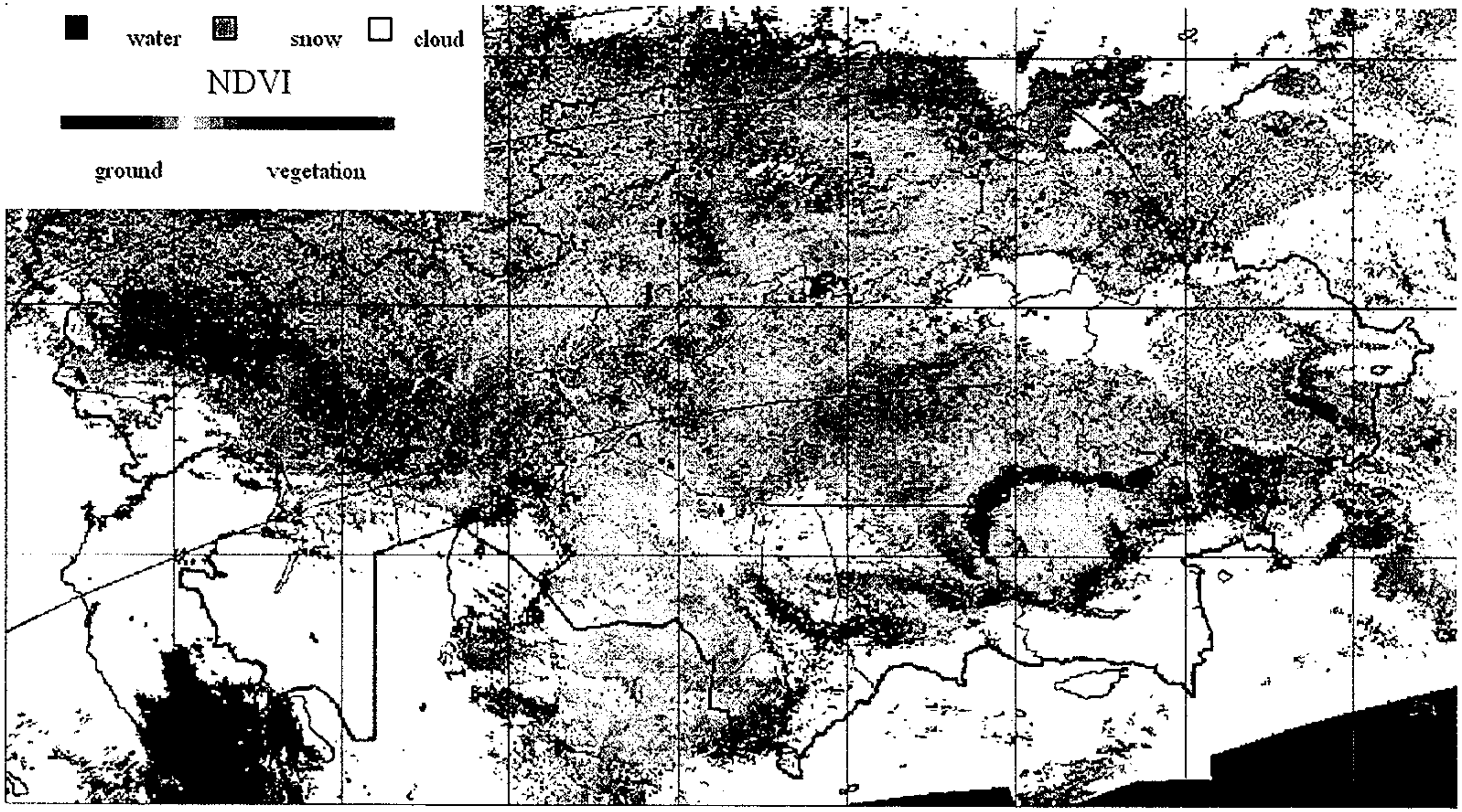


Figure 38. Annual Monitoring

Annual monitoring

8 May 1998

Figure 39. Annual Monitoring

Annual monitoring

22 May 1998

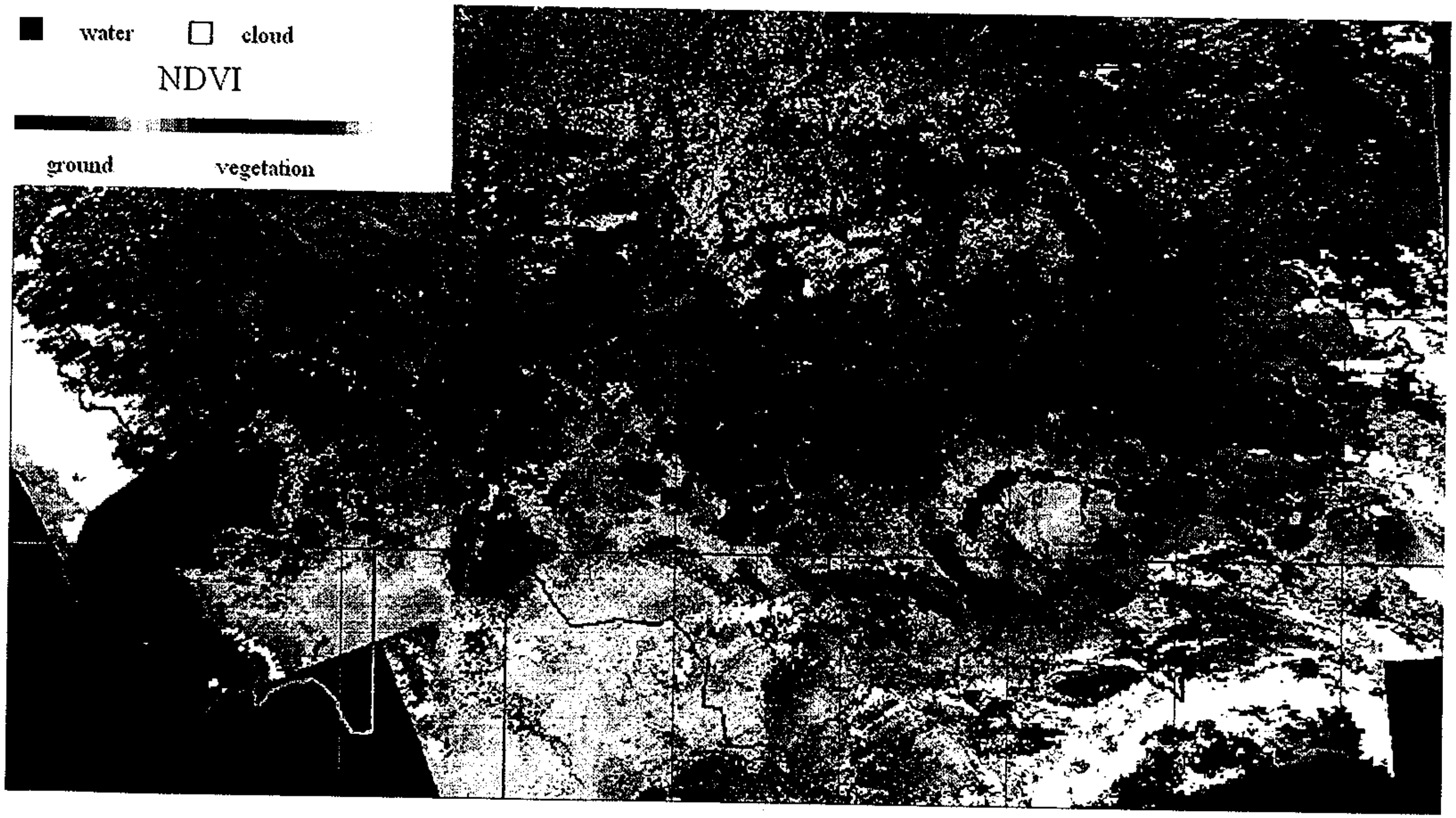


Figure 40. Annual Monitoring

Annual monitoring

15 June 1998

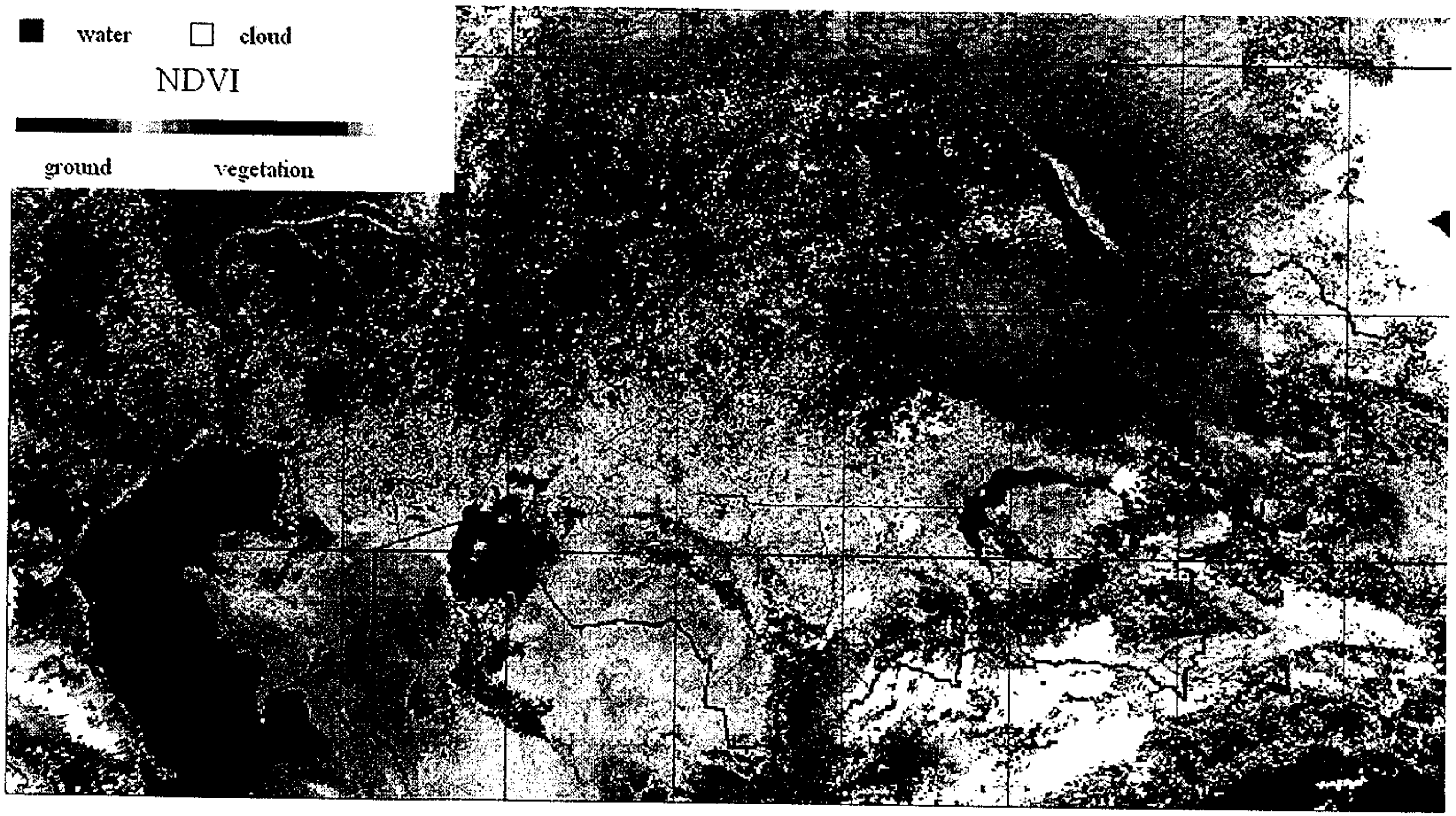


Figure 41. Annual Monitoring

Annual monitoring

27 June 1998

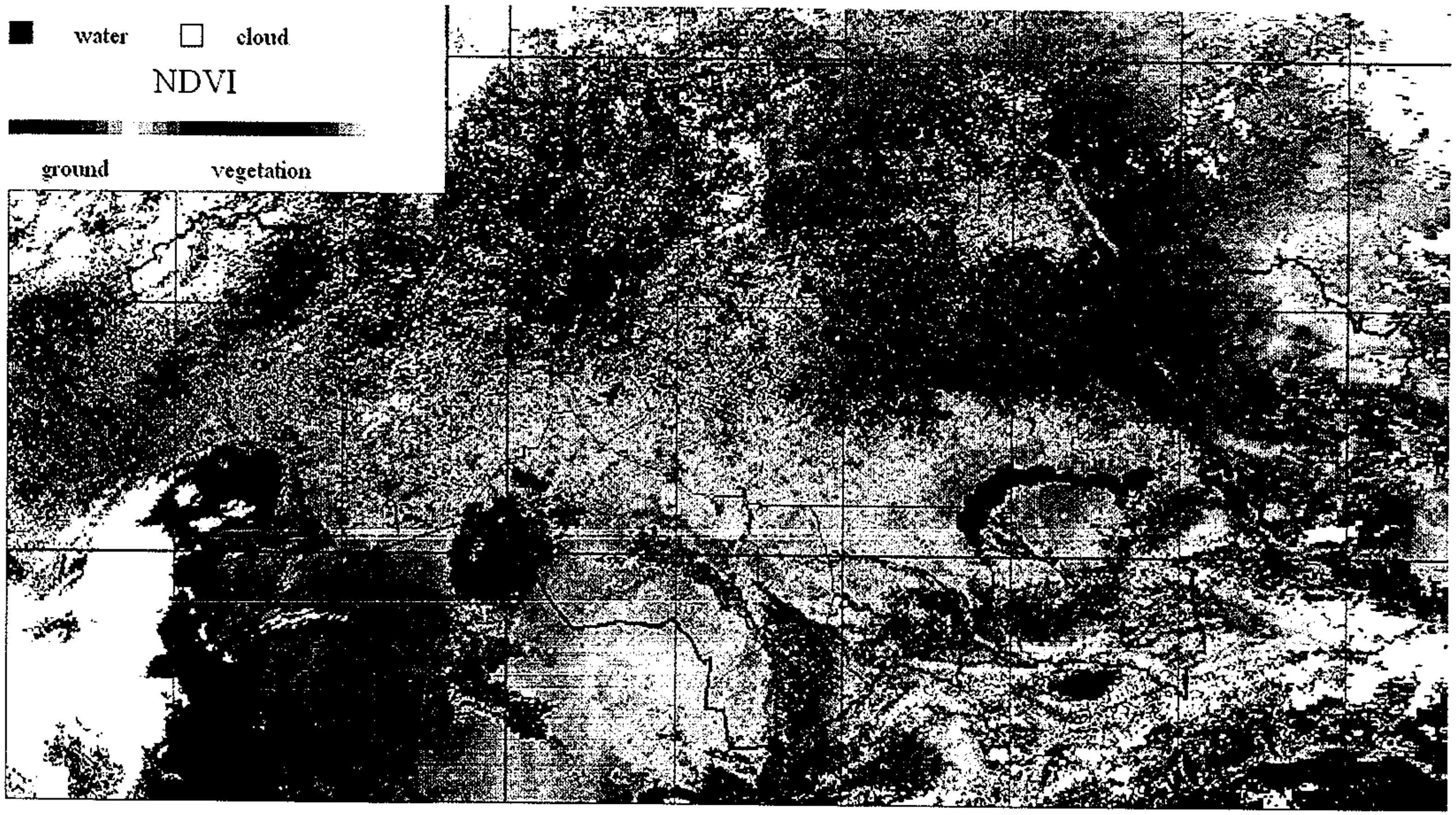


Figure 42. Annual Monitoring

Annual monitoring

10 July 1998

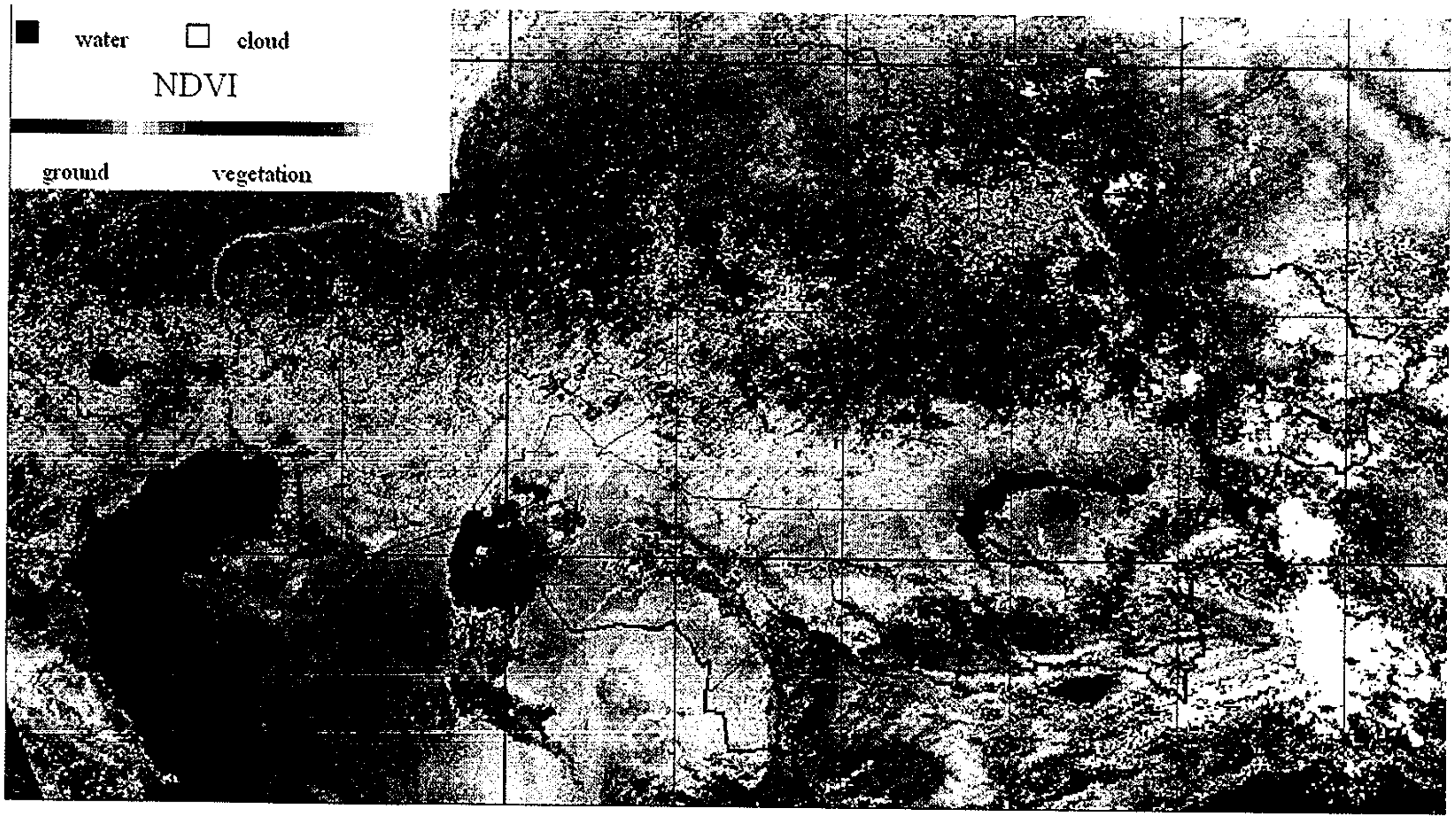


Figure 43. Annual Monitoring

Annual monitoring

16 July 1998

Figure 44. Annual Monitoring

Annual monitoring

25 July 1998

Figure 45. Annual Monitoring

Annual monitoring

2 August 1998

Figure 46. Annual Monitoring

Annual monitoring

10 August 1998

Figure 47. Annual Monitoring

Annual monitoring

20 August 1998

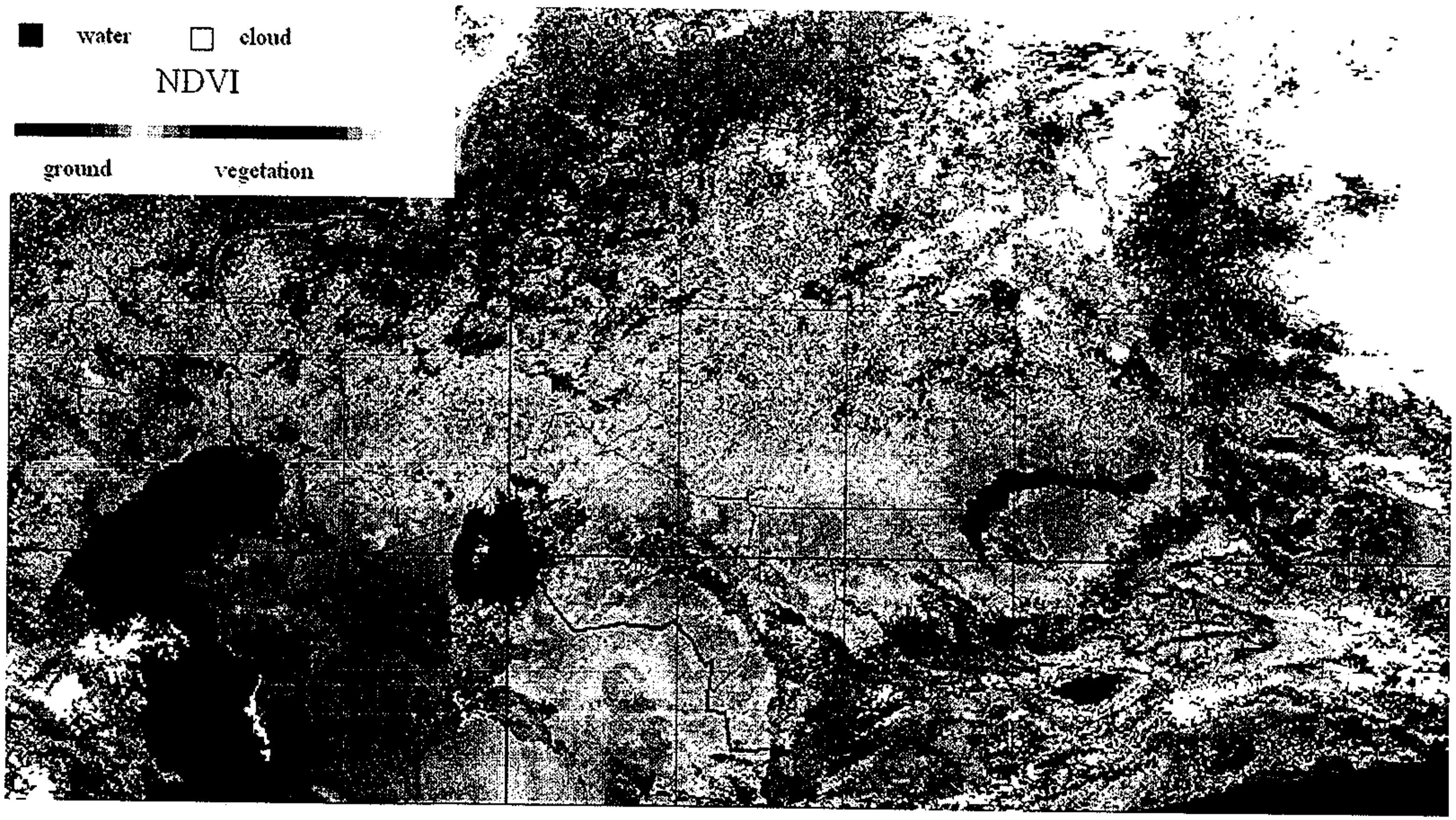


Figure 48. Annual Monitoring

Monitoring of Snow Cover, 2000

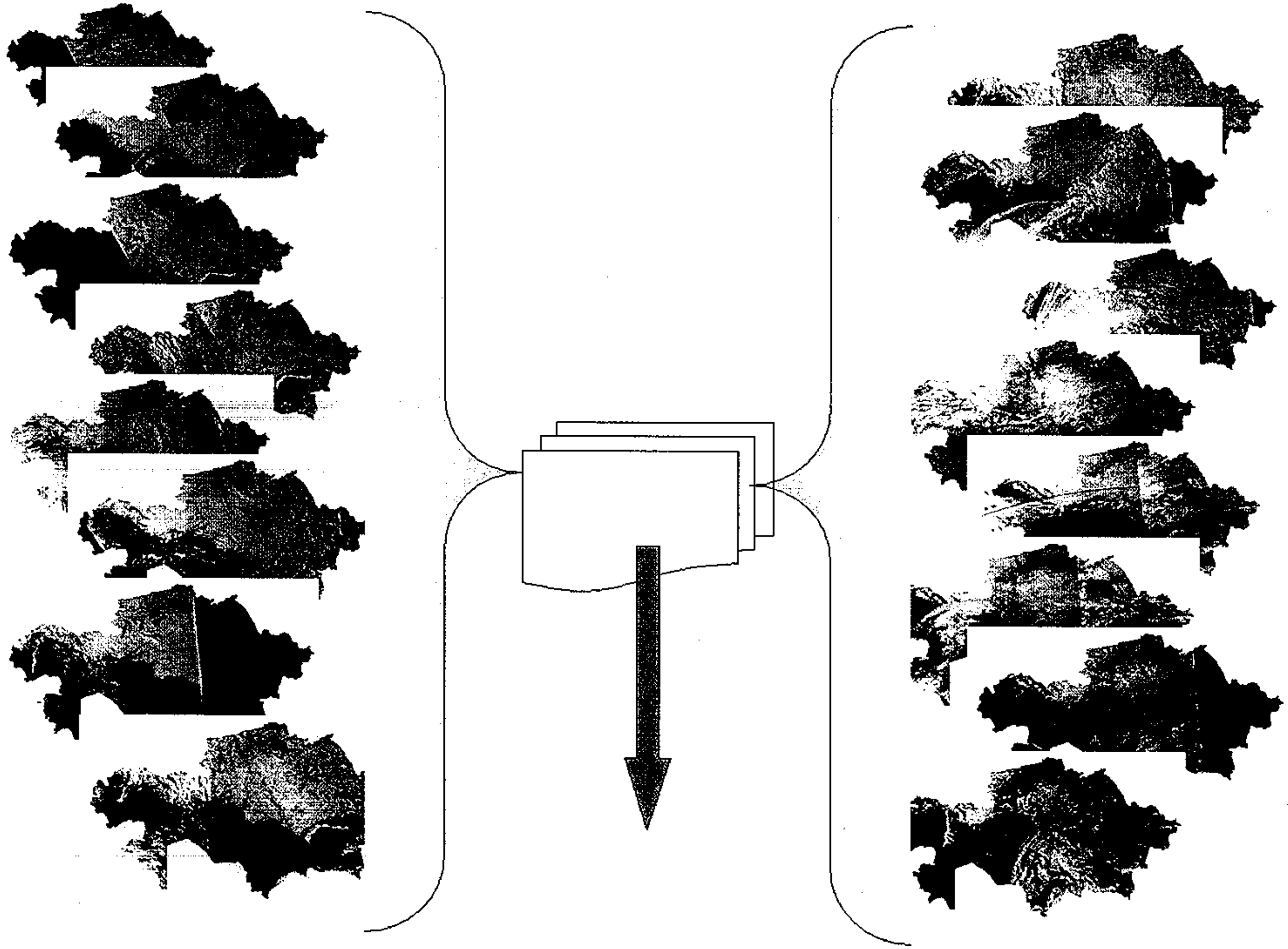


Figure 49. Monitoring of snow cover

Summary results 2000

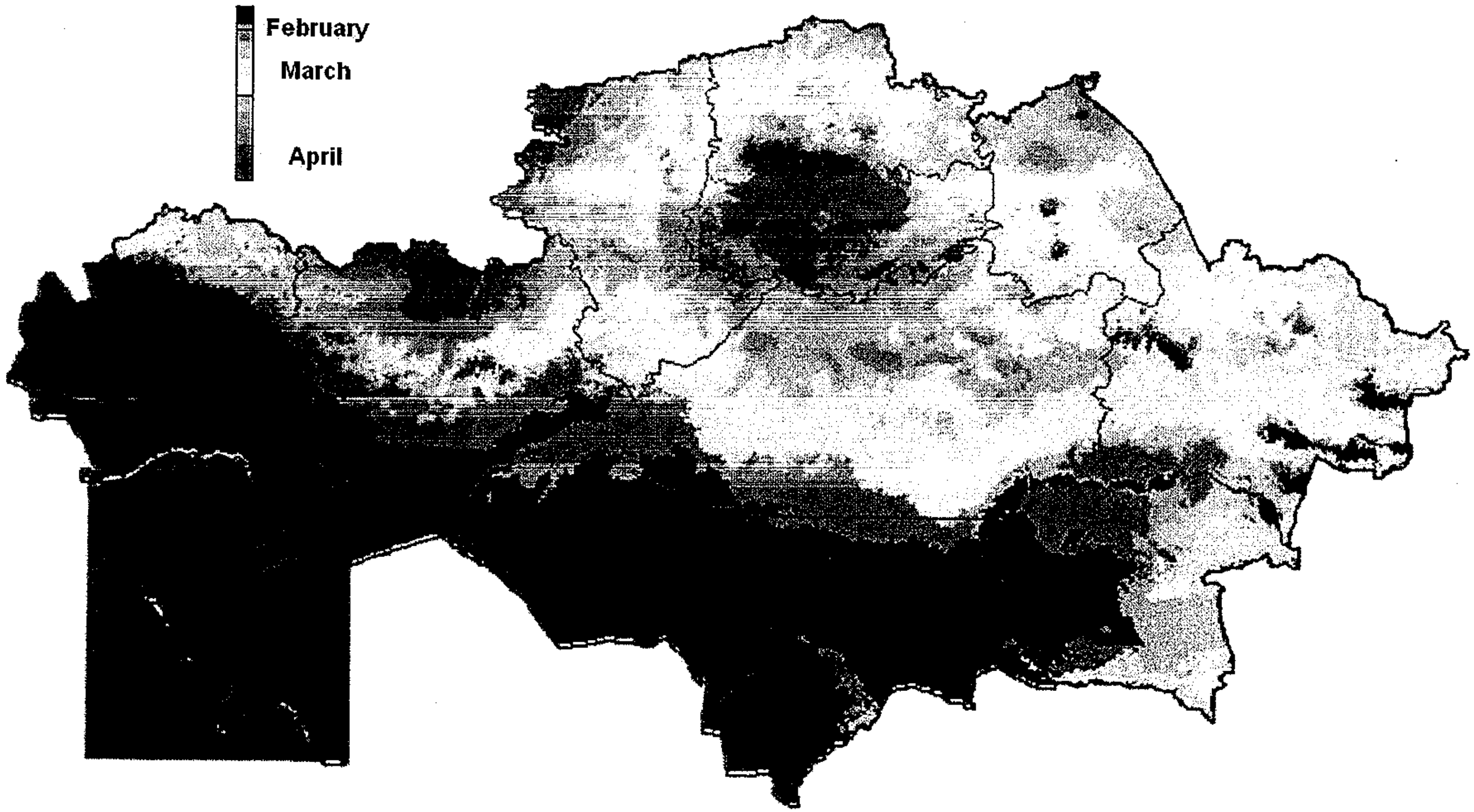


Figure 50. Summary results 2000

Estimation of Snowing Areas

NDVI map

Figure 51. NDVI Map

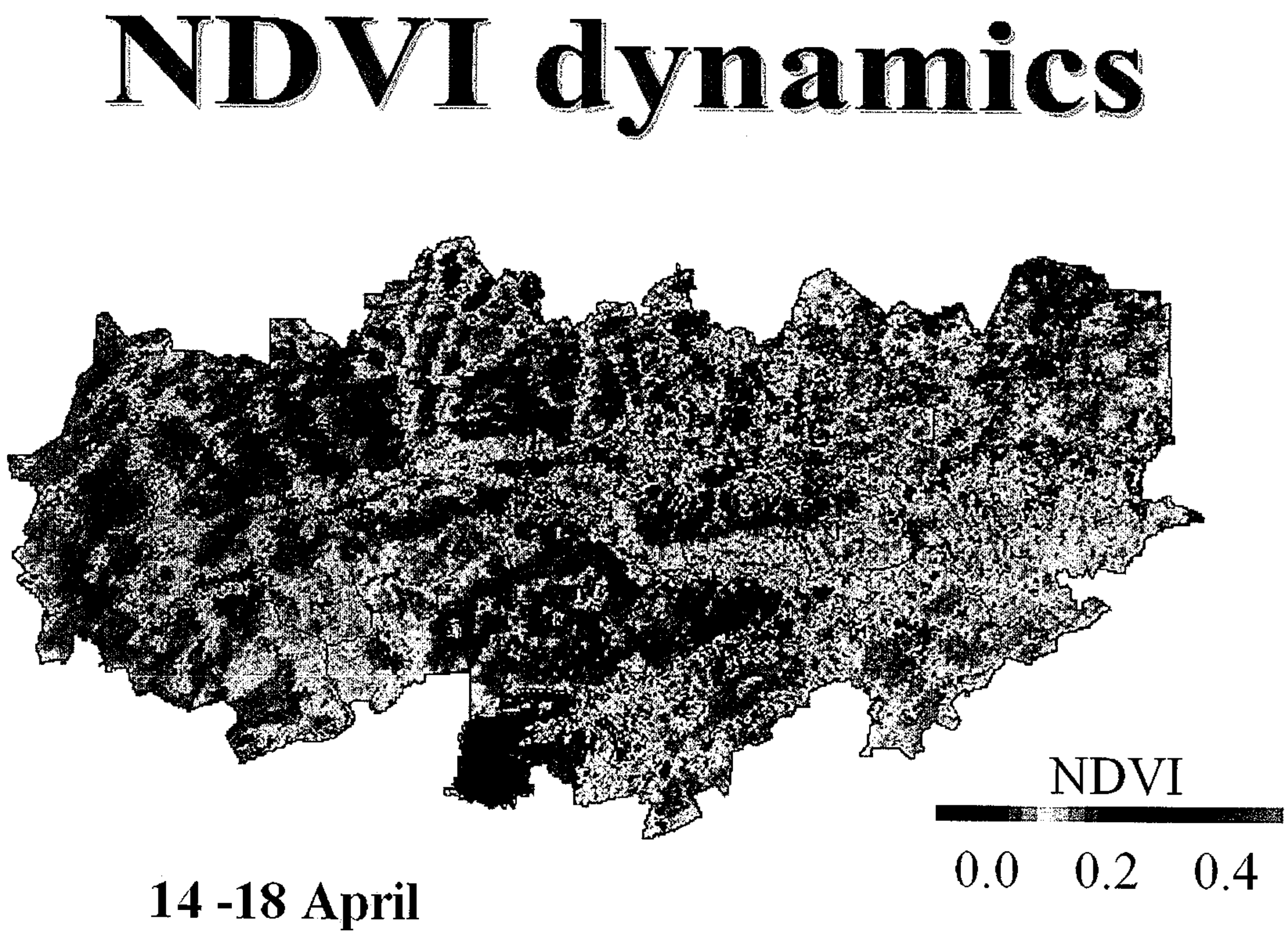


Figure 52. NDVI dynamics, April 14-18

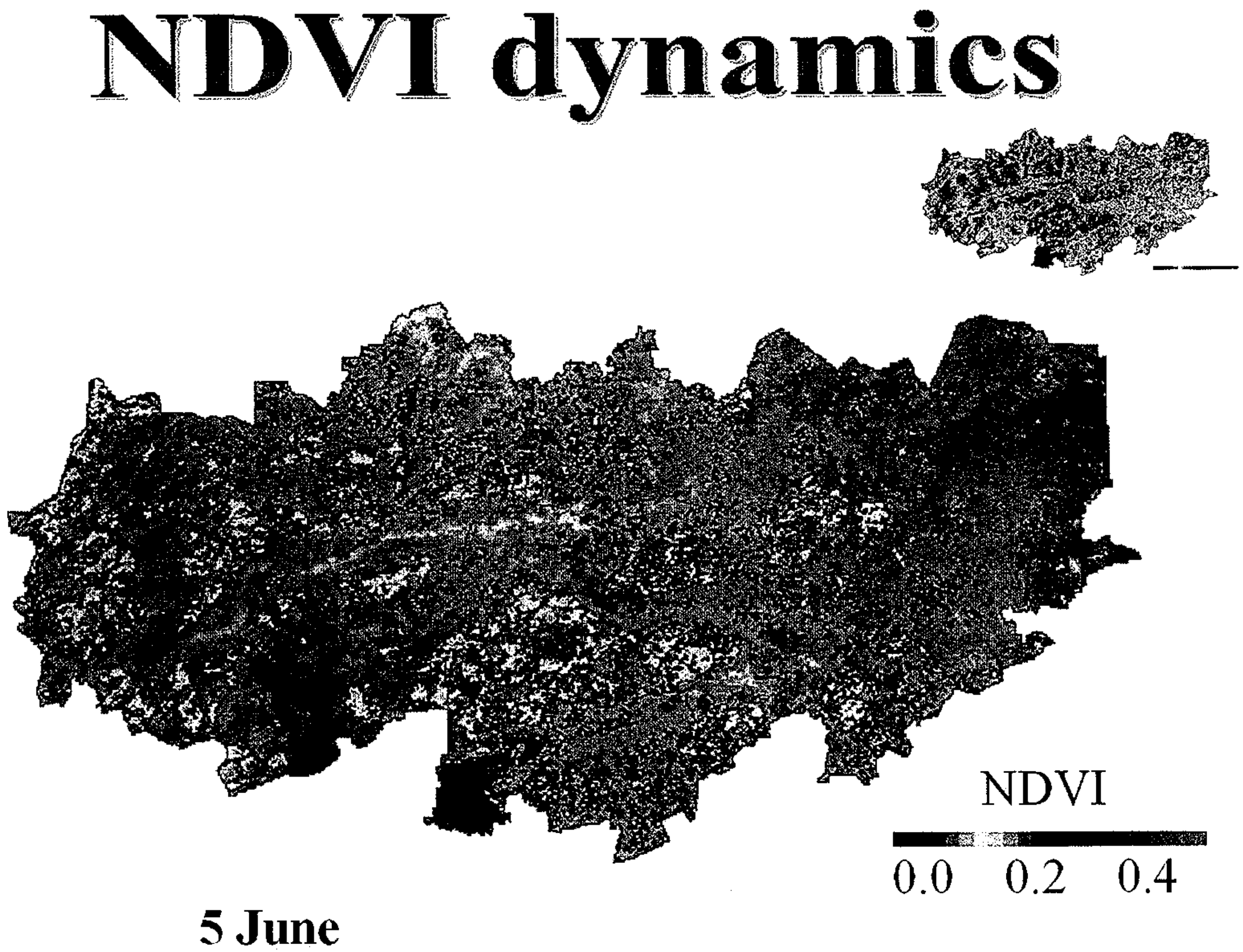


Figure 53. NDVI dynamics, June 5

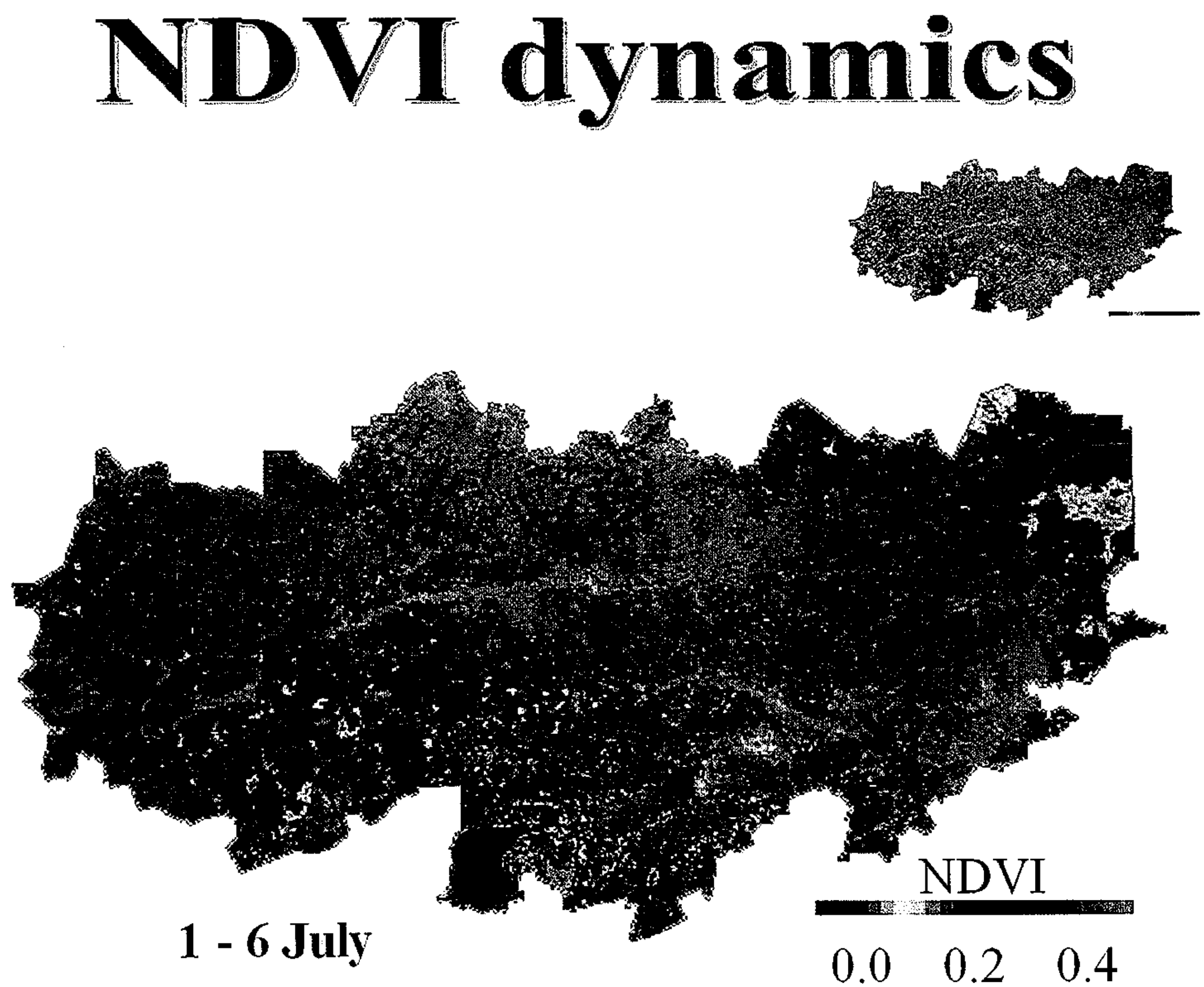


Figure 54. NDVI dynamics, July 1-6

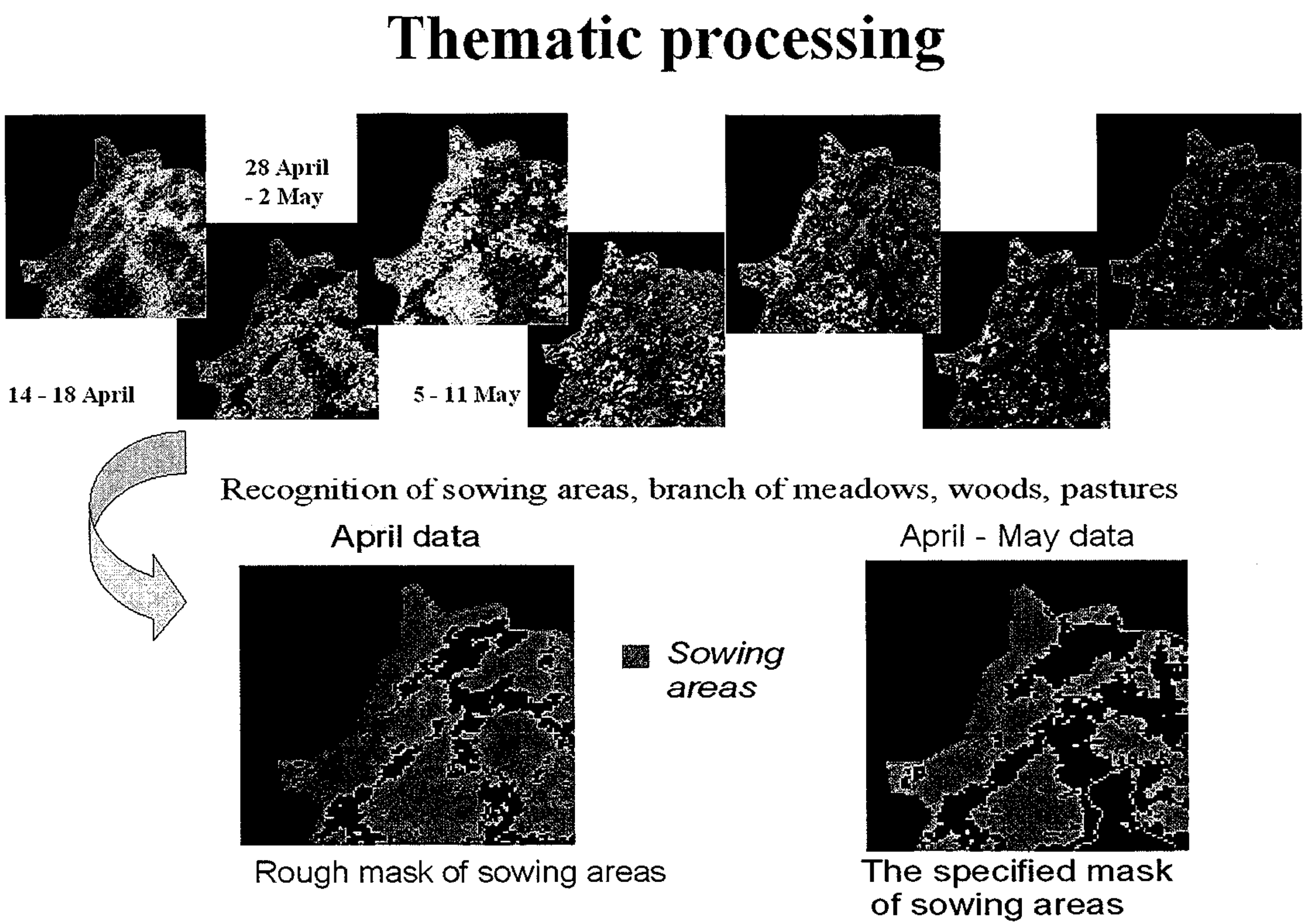


Figure 55. Thematic processing

Agricultural Lands Mask for Akmola region

Figure 56. Agricultural Land masks of Akmola region

Agricultural Lands Mask for North Kazakhstan region

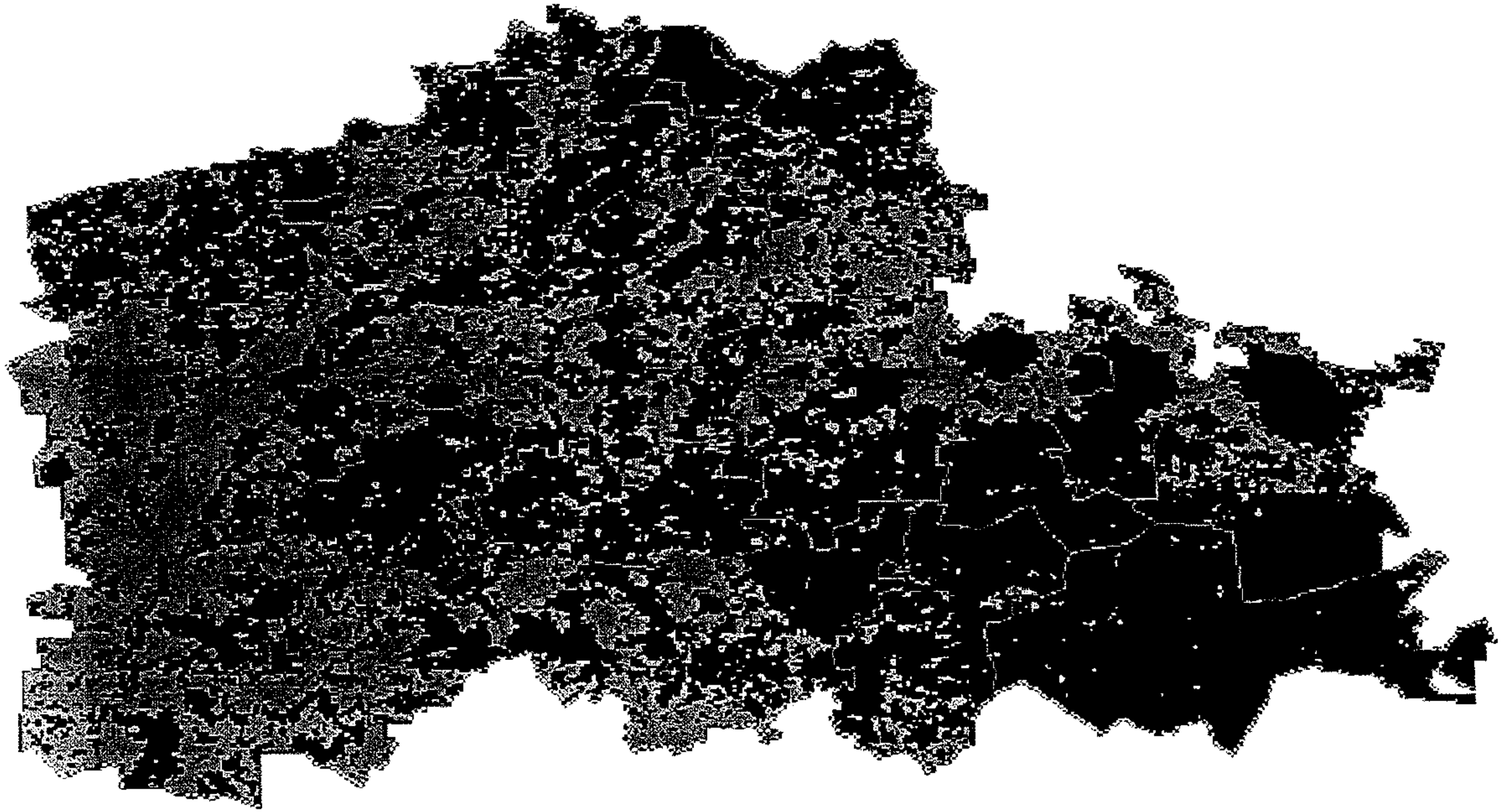


Figure 57. Agricultural Land masks of North Kazakhstan

Dynamics of mean VCI values 1986-1997

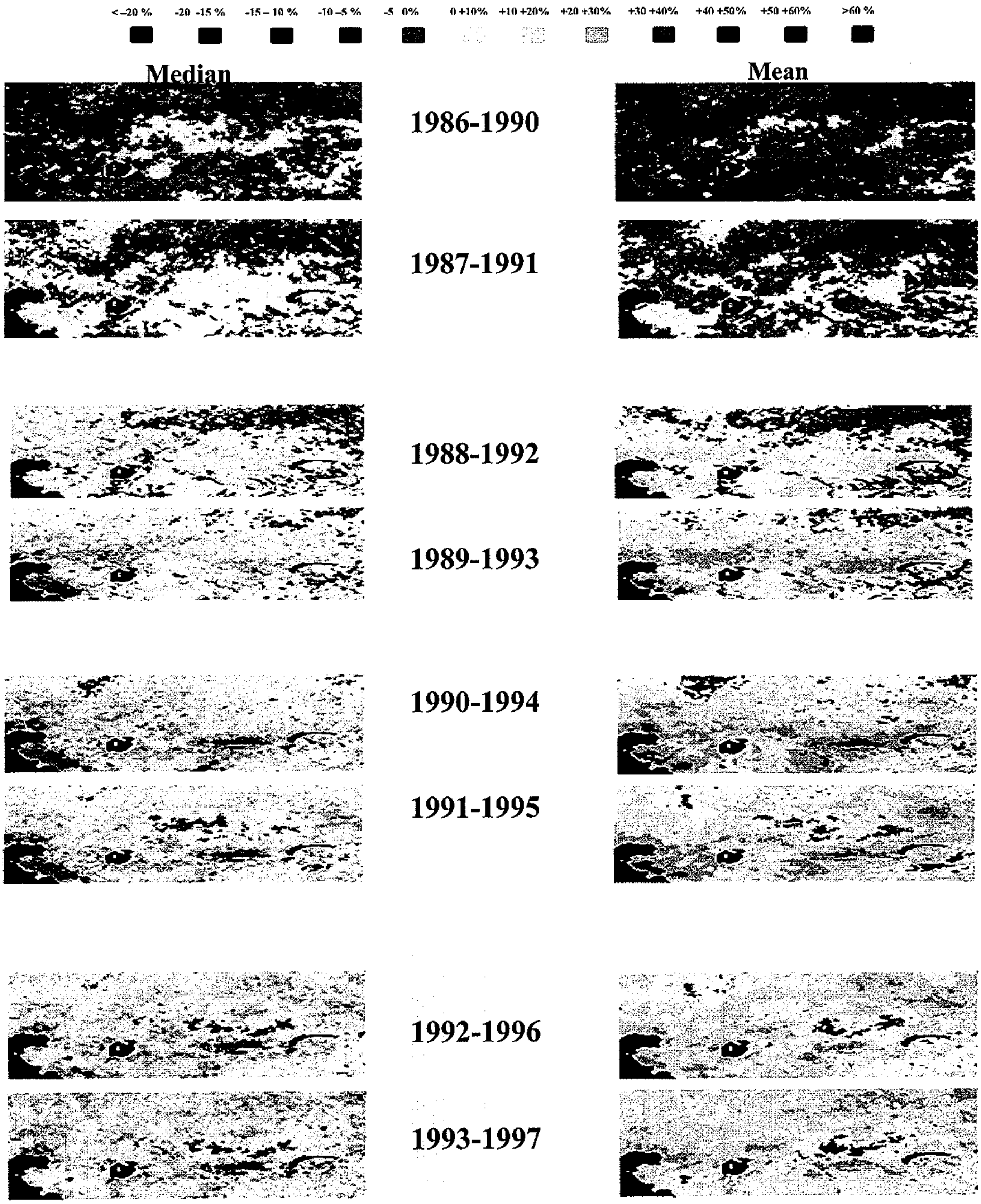
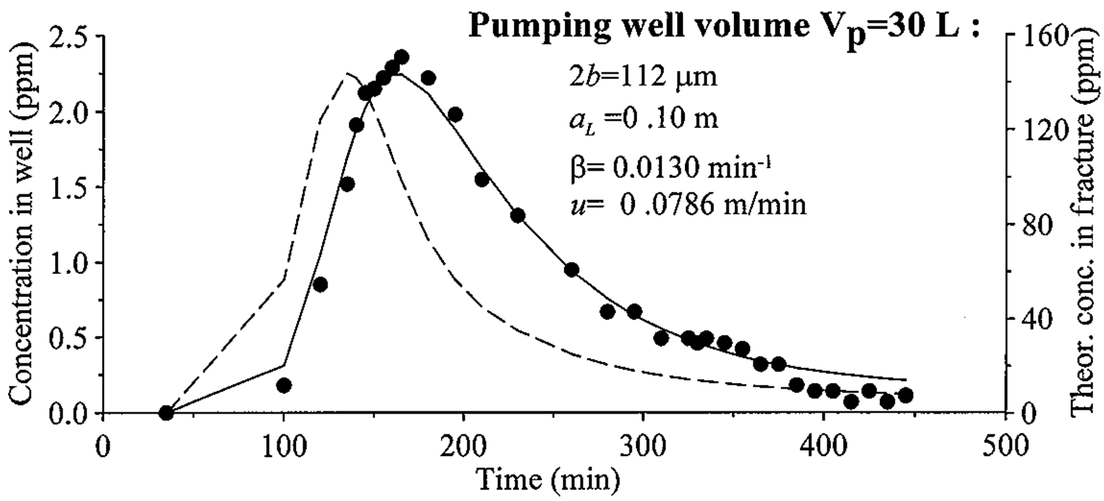


Figure 58. Dynamics of mean VCI values 1986-1997

Exponential distribution of concentration at the inlet
Number of fractures:20



● ● ● experimental concentration in pumping well

———— theoretical concentration in pumping well

– – – – – theoretical concentration at fracture outlet

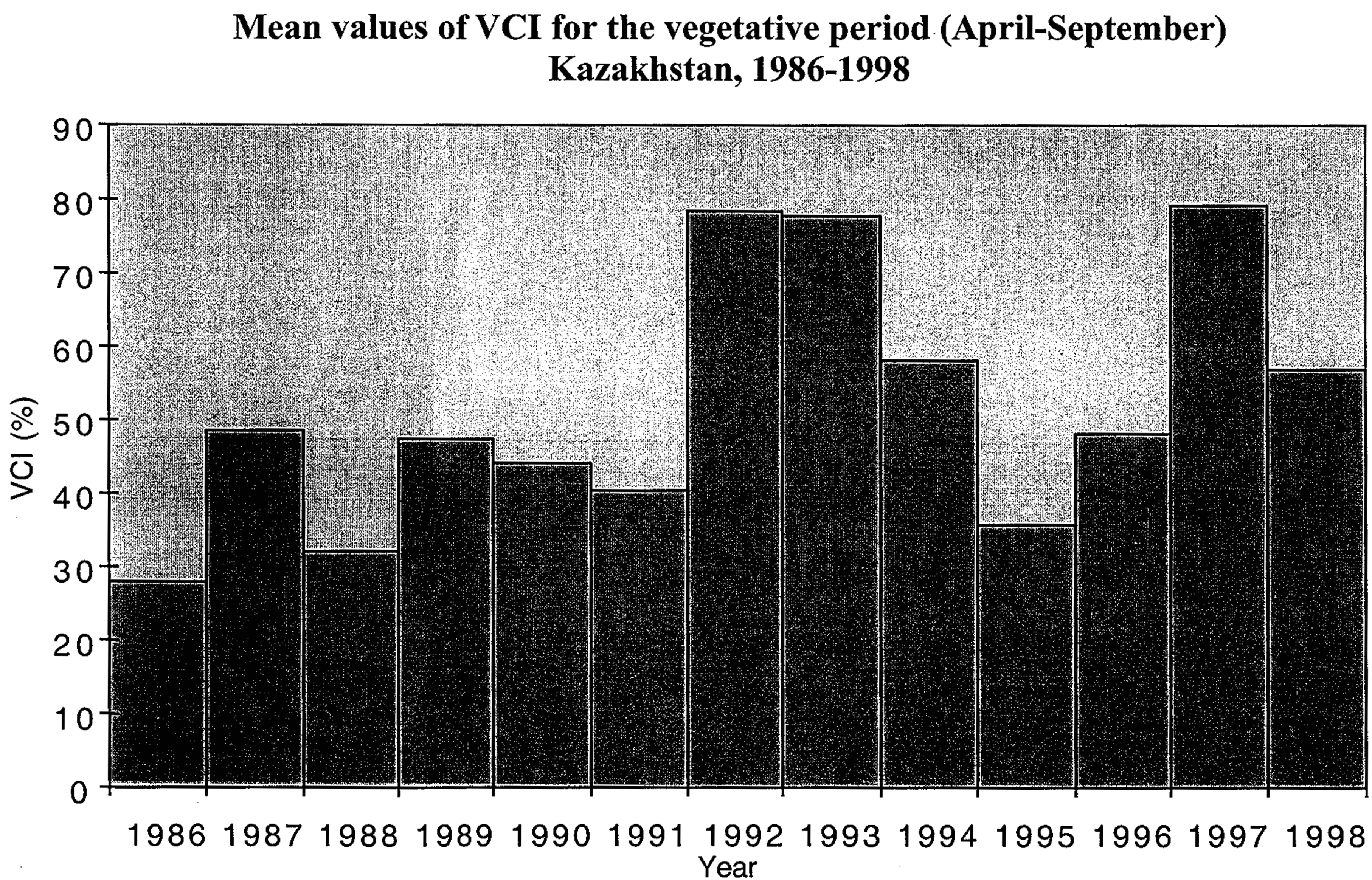


Figure 59. Mean values of VCI for the vegetative period (April-September), Kazakhstan, 1986-1998

Comparison of annual multi-year Vegetation Condition Index for the period of 1986-1990 and 1993-1997

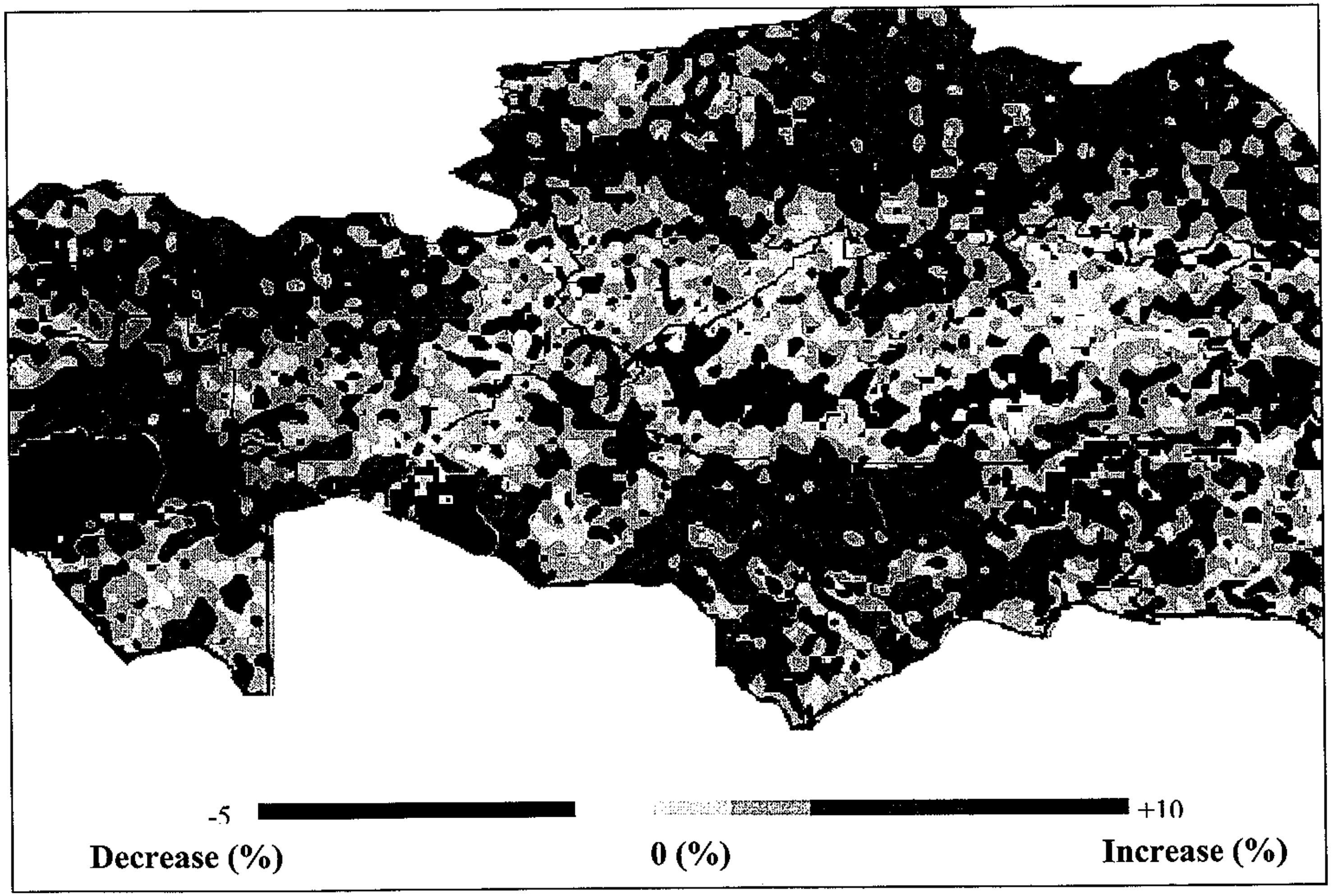


Figure 60. Comparison of annual multi-year Vegetation Condition Index
for the period of 1986-1990 and 1993-1997

Yield (a) and Yield Stability (b) of Agricultural Lands of Kazakhstan

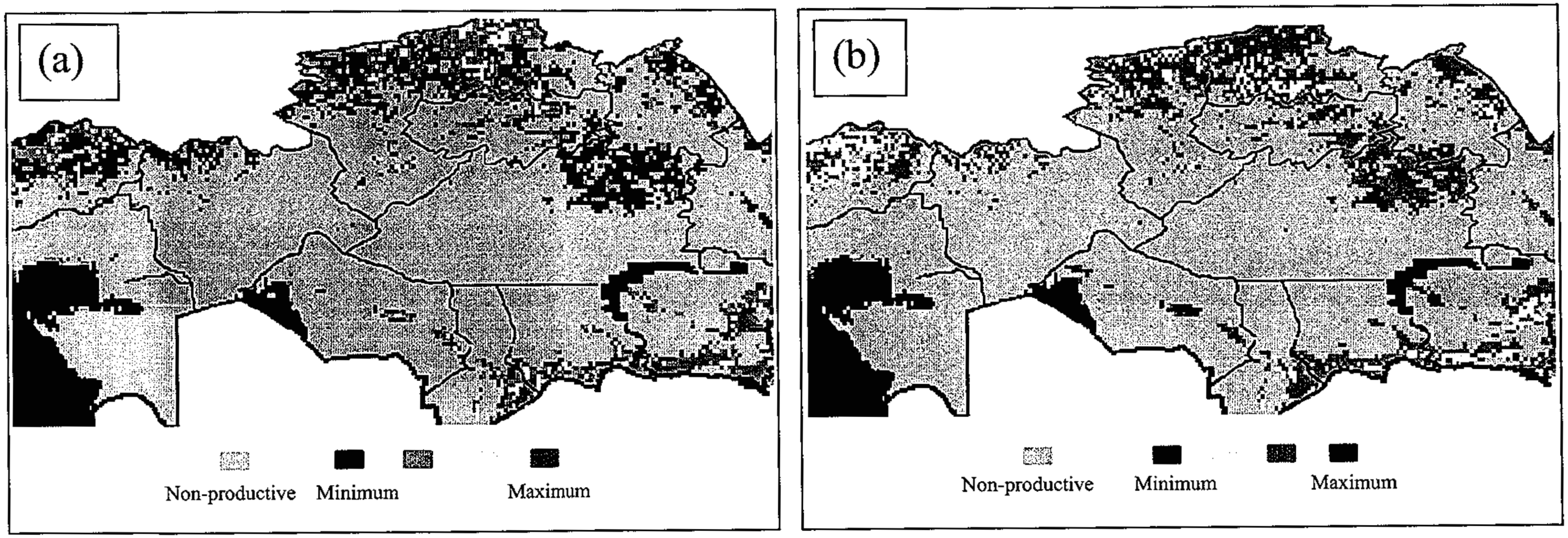
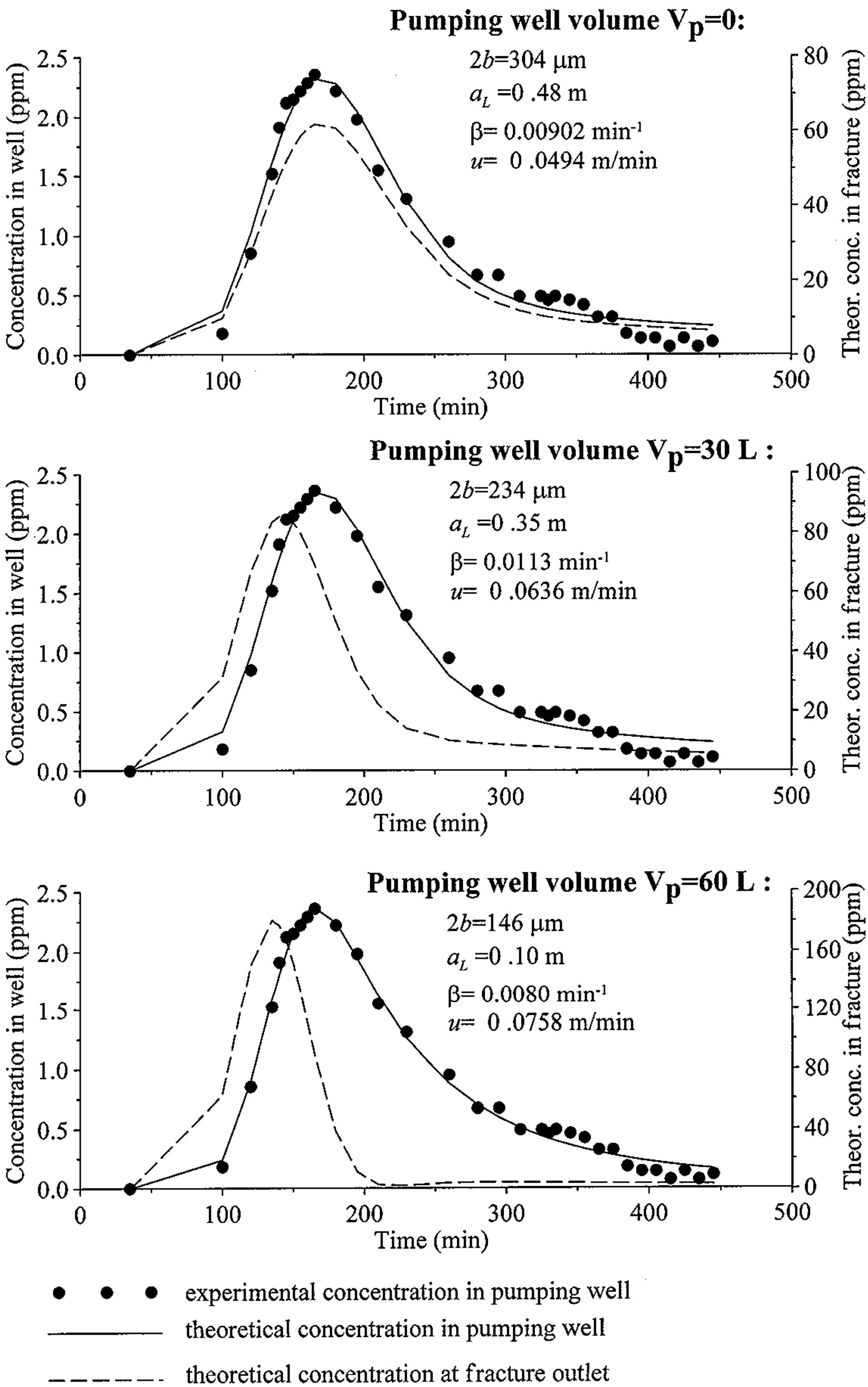


Figure61. Yield (a) and Yield Stability (b) of Agricultural Lands of Kazakhstan


Pumping well volume V_p=0:
$2b$=304 μm
a_L =0 .48 m
β= 0.00902 min^{-1}
u= 0 .0494 m/min
Concentration in well (ppm)
Theor. conc. in fracture (ppm)
Time (min)
Pumping well volume V_p=30 L :
$2b$=234 μm
a_L =0 .35 m
β= 0.0113 min^{-1}
u= 0 .0636 m/min
Concentration in well (ppm)
Theor. conc. in fracture (ppm)
Time (min)
Pumping well volume V_p=60 L :
$2b$=146 μm
a_L =0 .10 m
β= 0.0080 min^{-1}
u= 0 .0758 m/min
Concentration in well (ppm)
Theor. conc. in fracture (ppm)
Time (min)
experimental concentration in pumping well
theoretical concentration in pumping well
theoretical concentration at fracture outlet

6. Impact, Relevance and Technology Transfer

The results of this project will help Kazakhstan to start using new remote sensing technology for monitoring drought, vegetation conditions, sowing areas, snow cover, and temperature. The delivered hardware, software, proposed concept and methods, laid the foundation for a new, complete and efficient monitoring system. This system is the main contributor to a program of early warning crop and hazardous pasture condition assessment and prediction of agricultural production. The findings of this project help to increase the accuracy of agricultural production estimates, spatial distribution of production and timeliness of delivery of these estimates to customers. These improvements, in turn, help to develop a more efficient system for management of water resources and to improve agricultural planning. Since satellite data has global coverage, this system will serve as a prototype for similar systems in other parts of the developing world where ground observations are limited or not available at all.

The main beneficiary institutions in Kazakhstan are, first, our collaborators, the Institute for Space Research, and the National Meteorological Administration; the other institutions to benefit include the Ministries of Agriculture, Environment, Water Resources and Kazah Government in general.

The findings of this project were tested on large areas located in various ecological zones with different climates and with different levels of economic development.

The resulting new capacity of Kazakhstan includes:

High Resolution Picture Transmission (HRPT) receiving station, tracking antenna, positioner and receiver/demodulator/sectorizing subsystems for receiving NOAA polar-orbiting satellite signal; on-line PC for data collection and initial processing; image processing hardware and software for data processing, storage and distribution; algorithms for converting satellite radiances into the Vegetation Indices; algorithms for converting the vegetation indices into ground-derived environmental and agricultural characteristics (seasonal dynamic of pasture and crop conditions, and productivity) at test sites; drought detection and monitoring; expertise for data receiving, processing and interpretation.

7. Project Activities/Outputs

Dr. A. Gitelson (Israel) visited Kazakhstan (Almaty) met with entire Kazah team at the Kazah Institute for Space Research. The goal of this meeting was to control the quality of the 1998 field experiments data; to process and analyze them together with the team; to train team members to work with radiometers; to control the results and to process them; to transfer the expertise of working with HRPT station, receiving images and preliminary interpretation of the results. Also, the 1995 near real-time GVI data were transferred for the assessment of pasture and crop conditions, analysis of drought situation and delivery of these data to users. We also informed the AID officer in K (on May 25) and the decision and policy makers at the Ministries of Agriculture, Economics, Environment, Science and Technology (on May 26) on the result of the project and the current drought situation in K.

Dr. Kogan (USA) visited Israel (Beer-Sheva and Sede-Boker) to meet with Dr. A. Gitelson at the Institute for Desert Research of Ben-Gurion University of the Negev. The goal of this meeting was to analyze the 1997-99 experimental data, historical and current satellite and ground data, and to discuss the final results, and to write the final report for this project.

The results of two AID funded projects have been published:
(a) in English

Gitelson A., Kogan F., Zakarin E., Spivak L. Validation of AVHRR-based drought monitoring tool with ground data // International Geoscience and Remote Sensing Symposium (IGARSS'96) Lincoln, Nebraska USA, 1996.

Zakarin E., Spivak L. Early Determination and Monitoring of Droughts in Kazakhstan // GIS in Agricultural Research: Awareness Package. UNEP/ DETA/TR.97-9.

Spivak L., Terekhov A., Muratova N., Arkhipkin O.- The method of early drought detection with AVHRR/NOAA data // IGARSS'97. Singapore, 1997.

Gitelson A., Kogan F., Zakarin E., Spivak L. Using AVHRR data for Quantitive Estimation of Vegetation Conditions: Calibration and Validation // Adv. Space Research. 1998. Vol. 22. P. 673-676.

Sultangazin U., Zakarin E., Spivak L., Arkhipkin O., Muratova N., Terekhov A. Monitoring of temperature Anomalies in the former Semipalatinsk Nuclear Test Site // C. R. Acad. Sci. Paris, Serie Iib, Metodologie, instrument. 1998 t.326,. P.135-140.

Zakarin E., Spivak L., Azbenov V., Arkhipkin O., Muratova N., Terekhov A. Estimation of the Republic of Kazakhstan Cereal Areas Using Remote Sensing Data // IGARSS'98. Seattle, 1998.

Sultangazin U., Zakarin E., Spivak L., Arkhipkin O., Muratova N., Terekhov A. Detection of Anomalous Effects in the Semipalatinsk Nuclear Test Site with Remote Sensing // IGARSS'98. Seattle, 1998.

Spivak L.F., Arkhipkin O.P., Muratova N.R., Terehov A.G. Joint thematic MSU-SK and NOAA AVHRR data processing for estimation of cereal areas // IGARSS'99. Hamburg, 1999.

Terehov A.G., Muratova N.R., Arkhipkin O.P., Spivak L.F. Agroclimatic Zoning of Kazakhstan Territory Using Remote Sensing Data IGARSS'2000. Honolulu, 2000.

Terehov A.G., Muratova N.R., Arkhipkin O.P., Spivak L.F. Identification Methods of Desertification Centers Using Remote Sensing Data // IGARSS'2000. Honolulu, 2000.

(b) in Russian

Zakarin E.A., Spivak L.F., Turganbaev E.S., Muratova N.R. Geoinformation system of Semipalatinsk nuclear test site // ARCREVIEV, 1998, _3. pp.14-15

Arkhipkin O.P., Presnyakov A.A. Effect of optical features of materials and screening for heat transfer processes (on the example of the "Temir" space experimant) // Izvestya of the Ministry of science-academy of sciences, RK. Physics and mathematics. 1996. _3. - pp. 9-14.

Sulatngazin U.M., Zakarin E.A., Spivak L.F., Arkhipkin O.P., Muratova N.R., Terekhov A.G. Remote sensing of temperature anomalies on the Semipalatinsk nuclear test site // Reports of the Ministry of science-academy of sciences, RK. 1997. _2. - pp.51-54.

Veselov V.V., Spivak L.F. Basis of structure modeling of hydro systems. Almaty: Gylym, 1997. - 216 p.

Zakarin E.A., Spivak L.F., Arkhipkin O.P., Muratova N.R., Terekhov A.G. – Remote sensing methods in agriculture of Kazakhstan. Almaty. Gylym, 1999 – 176p.

Zakarin E.A., Spivak L.F., Azhbenov V.K., Arkhipkin O.P., Muratova N.R., Terekhov A.G. – Technology of crop areas estimation in the north regions of Kazakhstan on the base of NOAA AVHRR data // Reports of the Ministry of science-academy of sciences, RK. 1999. _3. – pp.92-97.

Spivak L.F., Arkhipkin O.P., Muratova N.R., Terekhov A.G. Information technology for identification of desertification zones on the remote sensing data // Proc. Inten. Conf. "Problems of numeric mathematics and information technologies" (Almaty, March, 25-26, 1999). Almaty: 1999. – pp. 335-336

8. Project Productivity

All project goals were accomplished. A non-conventional system, which uses NOAA operational polar-orbiting satellites for quantitative assessments of pasture and crop conditions and productivity in Kazakhstan, was developed and launched.

In addition to the project goals several other important tasks were accomplished:

- Calibration of satellite-derived indices versus ground data at experimental sites, located in different climatic zones of Kazakhstan;
- Monitoring of drought and vegetation conditions since 1997;
- Monitoring of surface temperature since 1998;
- Monitoring of sowing areas since 1998;
- Monitoring of snow cover since 2000.

9. Future work

We suggest launching a system for receiving MODIS data in Kazakhstan. This would allow improvement in the quality of monitoring and its spatial resolution.

We also suggest using developed system as a prototype for other Middle Asian countries. The projects should be funded to launch such systems in other Middle Asian countries and to help them to develop near real-time monitoring of drought, crop and pasture conditions and their productivity, sowing areas, temperature and so on.

10. References

Aladin N.V., I.S. Plotnikov I.S., and W.T.W. Potts. 1995. The Aral Sea desiccation and possible ways of rehabilitating and conserving its northern part. Environmetrics 6(1):17-29.

Brada, J. C. 1986. The variability of crop production in private and socialized agriculture: evidence from Eastern Europe. J. of Political Economy 94:545-563.

Cracknel, A.P. 1997. *The Advanced Very High Resolution Radiometer,* Taylor & Francis, Great Britain, 534.

Cresswell, W., S. Bright, P. Carry, J. Chaves, J. Freile, A. Gretton, A. Zykin, R. McGregor, D. McLaughlin, S. Yerokhov, N. Berezovikov, and R. Mellanby. 1999. Important wetlands in northern and eastern Kazakstan. Wildfowl 50:181-194.

Funakawa, S., T. Kosaki, N. Ishida, R. Suzuki, and E. Karbozova. 2000. Salt-affected soils under rice-based irrigation agriculture in southern Kazakhstan. Geoderma 97(1-2):61-85

Gates, D.M. 1970. Physical and Physiological Properties of Plants, *Remote Sensing with Specific Reference to Agriculture and Forestry.* National academy of Sciences, Washington, D.C., 224-252.

Gitelson, A.A. and M.N. Merzlyak, 1994. Spectral reflectance changes associated with autumn senescence of *Asculus hippocastanum* and *Acer platanoides* leaves. Spectral features and relation to chlorophyll estimation. *J. Plant Physiol.* 143: 286-292.

Gitelson, A., Kaufman, Y., and Merzlyak, M. 1996. Use of a Green Channel in Remote Sensing of Global Vegetation from EOS-MODIS. Remote Sensing of Environment, Vol. 58, 289-298.

Gitelson, A.A. and M.N. Merzlyak, M.N. 1997. Remote estimation of chlorophyll content in higher plant leaves. *Int. J. Remote Sens.,* 18, 2691-2697.

Gitelson, A.A., and M.N. Merzlyak, 1994a. Quantitative estimation of chlorophyll-a using reflectance spectra: experiments with autumn chestnut and maple leaves. *J. Photochem. Photobiol.* B: Biol., 22: 247-252.

Gol'tsberg, I.A. (Ed.), 1972. Agroclimatic Atlas of the World, Hydrometizdat, 212 p.

Goward, S.N. and Dye, D.G. 1987. Evaluating North American net primary productivity with satellite observations. *Advancement in Space Research,* 7, 165-174.

Goward, S.N., B.Markham, D.G.Dye, W.Dulaney, J.Yang 1991. Normalized Difference Vegetation Index measurements from the Advanced Very high Resolution Radiometer, *Remote Sens. Environ.,* 35, 257-277.

Grace, J.D. 1998. Caspian production, export, investment outlooks sized up. Oil and Gas Journal 96(34):67-71.

Gray, J. 2000. Kazakhstan. A review of farm restructuring. World Bank Technical Paper No. 458:1-64.

Gurgen, E., I. Izvorski, R. van Rooden, H. Snoek, J. Craig, and J. McHugh. 1999. Economic reforms in Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan. IMF Occasional Papers no.183 pp. 1-77.

Gutman, G.G., 1991. Vegetation Indices from AVHRR Data: An Update and Future Prospects, *Remote Sens. Environ.*, 35, 121-136.

Justice, C.O., B.N. Holben, M.D. Gwynne, 1986. Monitoring East African vegetation. *Int. J. Remote Sensing,* 7: 1453.

Justice, C.O. and J.R.G.Townshend, 1994: Data sets for global remote sensing: lessons learnt. *Int. J. Rem. Sens.*, 15: 3621-3639

Justice, C.O., Holben, B.N., Gwynne, M.D. 1986. Monitoring East African vegetation. *Int. J. Remote Sens.,* 7, 1453.

Karibdzhanov, E.S., and M.A. Taishibayev. 1998. The oil and gas industry in Kazakstan. Nationalities Papers 26(3):557-564.

Kazakhstan Land Use Agency. 1999. National Report on State of Land Use in Kazakhstan. Kazakhstan Land Use Agency: Astana.

Keyser D., A. Khabibullayev, and V. Moustafaev. 1999. Research for rehabilitating the Aral Sea region. Nature and Resources 35(2):26-37.

Kidwell, K. B. 1997. *Global Vegetation Index User's Guide.* Department of Commerce, NOAA/NESDIS, National Climate Data Center, Washington D.C., 52

Kogan, F.N., 1985. The impact of climate and technology on Soviet grain production. monograph series on Soviet Union Sponsored by Delphic Associates, DELFIC, 177p.

Kogan, F.N., 1987. Vegetation index for areal analysis of crop conditions. Proceedings of the 18th Conference on Agricultural and Forest Meteorology, AMS, W. Lafayette, pp.103-107.

Kogan, F.N. 1990. Remote sensing of weather impacts on vegetation in non-homogeneous areas. *Int. J. Remote Sens.,* 11, 1405- 1419.

Kogan, F.N. 1994. NOAA plays leadership role in developing satellite technology for drought watch. *Earth Observation Magazine*, September 1994, pp. 18-21.

Kogan, F.N. 1995a. Droughts of the Late 1980s in the United States as Derived from NOAA Polar Orbiting Satellite Data. *Bull. Amer. Meteor. Soc.* 76, 655-668.

Kogan, F.N. 1995b. Application of vegetation index and brightness temperature for drought detection. *Advancement in Space Research*, 15, 91-100.

Kogan, F.N. 1997. Global Drought Watch from Space. *Bull. Amer. Meteor. Soc.*, 78, 621-636.

Kogan, F.N. 2000. Global drought detection and impact assessment from space. In *Drought: A Global Assessment,* Ed. D. A. Wilhite, Vol. 1, Hazard and Disaster Series, Routledge, London-New York, 196-210.

Kogan, F. N. 2000. Satellite-Observed Sensitivity of World Land Ecosystems to El Niño/La Niña. *Remote Sensing of Environment*, 74:445-462.

Kogan, F and J. Sullivan 1993. Development of global drought-watch system using NOAA/AVHRR data. *Advancement in Space Research*, 13 (5): 219-222.

Kotlyakov, V.M. 1991. The Aral Sea basin: a critical environmental zone. Environment 33(1):4-9 and 36-38.

Kuznetsova, I.N. 1996. Southeasterly air mass transport as a factor of increased total beta-activity in eastern European Russia. Russian Meteorology and Hydrology 6:1-5.

Ladejinsky, W. 1934a. Collectivization of agriculture in the Soviet Union I. Political Science Quarterly 49(1):1-43.

Ladejinsky, W. 1934b. Collectivization of agriculture in the Soviet Union II. Political Science Quarterly 49(2):207-252.

Ladejinsky, W. 1938a. Soviet State Farms I. Political Science Quarterly 53(1):60-82.

Ladejinsky, W. 1938b. Soviet State Farms II. Political Science Quarterly 53(2):207-232.

Los, S.O., C.O.Justice, and C.J.Tucker (1994), A global 1 by 1 degree NDVI data set for climate studies derived from GIMMS continental NDVI data. *Int. J. Rem. Sens.*, 15: 3493-3518

Lutter, C., T. Chuvakova, G. Kazbekova, T. Sharmanov, V. Iyengar, and R. Barnes. 1998. Breast milk contamination in Kazakhstan: Implications for infant feeding. Chemosphere 37(9-12):1761-1772.

Malingreau, J.P., 1986. Global vegetation dynamics: satellite observations over Asia. *Int. J. Remote Sensing*, 7: 1121.

Mandel, W.M. 1942. Soviet Central Asia. Pacific Affairs 15(4):389-409.

Matzko, J.R., and B. Butler. 1999. ICBMs and the environment: assessments at a base in Kazakhstan. Post-Soviet Geography and Economics 40(8):617-628.

Micklin, P.P. 1988. Desiccation of the Aral Sea: a water management disaster in the Soviet Union. Science 241:1170-1176.

Myers, V.I. 1970. Soil, Water, and Plant Relations, *Remote Sensing with Specific Reference to Agriculture and Forestry.* National Academy of Sciences, Washington, D.C., 253-267.

NOAA, 1988. NOAA polar orbiter data users guide. NOAA-11 update. Ed K.B. Kidwell.

Ohring, G., K. Gallo, A. Gruber, W. Planet, L. Stowe, J.D. Tarpley, 1989. Climate and Global Change: Characteristics of NOAA Satellite Data. Eos. Trans., *Amer. Geophysical Union,* 70: 889-901.

Opdahl, R.W. 1960. Soviet agriculture since 1953. Political Science Quarterly 75(1):47-65.

Otarbaeva, B. 1998. A brief history of the Kazak people. Nationalities Papers 26(3):421-432.

Petr T., and V.P. Mitrofanov. 1998. The impact on fish stocks of river regulation in Central Asia and Kazakhstan. Lakes and Reservoirs: Research and Management 3(3-4):143-164.

Prince, S.D., and C.J. Tucker, 1986. Satellite remote sensing of rangelands in Botswana. *Int. J. Remote Sensing,* 7: 1555.

Rao, K.P., S.J. Holmes, R.K. Anderson, J.S. Winston, P.E. Lehr, editors, 1990. Weather Satellites: Systems, Data, and Environmental Applications. American Meteorological Society, Boston, 503 pp.

Rywkin, M. 1998. Kazakstan and the rest of Central Asia: fifteen shades of difference. Nationalities Papers 26(3):573-579.

Sanderson, S. 1994. Political-economic institutions. In: (W.B. Meyer and B.L. Turner II, eds.) Changes in Land Use and Land Cover: A Global Perspective. Cambridge University Press: New York. pp. 329-355.

Schatz, E.A.D. 2000a. Framing strategies and non-conflict in multi-ethnic Kazakhstan. Nationalism and Ethnic Politics 6(2):71-94.

Schatz, E.A.D. 2000b. The politics of multiple identities: lineage and ethnicity in Kazakhstan. Europe - Asia Studies 52(3):489-506.

Sykes, L.R., and G.C. Wiggins. 1986. Yields of Soviet underground nuclear explosions at Novaya Zemlya, 1964-1976, from seismic body and surface waves. Proc. Natl. Acad. Sci. USA. 83:201-205.

Sykes, L.R., J. Deng, and P. Lyubomirskiy. 1993. Accurate location of nuclear explosions at Azgir Kazakhstan, from satellite images and seismic data: implications for monitoring decoupled explosions Geophysical Research Letters 20(18):1919-1922

Terehov A.G., Muratova N.R., 2000a. Arkhipkin O.P., Spivak L.F. Identification Methods o Desertification Centers Using Remote Sensing Data // IGARSS'2000. Honolulu, 2000.

Terehov A.G., Muratova N.R., Arkhipkin O.P., Spivak L.F. 2000b. Agroclimatic Zoning of Kazakhstan Territory Using Remote Sensing Data IGARSS'2000. Honolulu, 2000.

Terekhov, A., N. Muratova, O. Arkhipkin, L. Spivak. 2000. Agroclimatic zoning of Kasakhstan territory using remote sensing data. Proceedings of IGARSS 2000.

Townsend, J.R.G., C.O. Justice, 1986. Analysis of the dynamics of African vegetation using the normalized difference vegetation index. *Int. J. Remote Sensing,* 7: 1435.

Townshend, J.R.G (1994) Global data sets for land applications from the Advanced Very High Resolution Radiometer: an introduction. *Int. J. Rem. Sens.*, 15: 3319-3332.

Townshend, J.R.G. and C.O. Justice (1986), Analysis of the dynamics of African vegetation using the Normalized Difference Vegetation Index. *Int. J. Remote Sens.*, 7, 1435-1447.

Treyvish, A.I. 2000. Economic shifts and links in the post-Soviet space: Problems of disintegration and integration. Izvestiya Akademii Nauk, Seriya Geograficheskaya No.3:9-22. (in Russian).

Tucker, C.J., J.R.G. Townshend, T.E. Goff, 1985. African Land Cover Classification Using Satellite Data. *Science*, 227, No. 4685, January 25: 369-375.

Tucker, C. J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8, 127-50.

Tucker, C. J. and B. J. Choudhury 1987. Satellite Remote Sensing of Drought conditions. *Remote Sensing of Environment*, 23, 243-251.

Tucker, C.J., Justice, C.O., Prince, S.D., 1986. Monitoring the grasslands of the Sahel 1984-1985. *Int. J. Remote Sensing,* 7: 1571.

Unganai L.S. and Kogan, F.N. 1998. Drought Monitoring and corn yield estimation in Southern Africa from AVHRR data. *Remote Sensing of Environment*, 63, 219-232.

van Dijk, A., S.L.Callis, C.M.Sakamoto, and W.L.Decker. 1987. Smoothing vegetation index profiles: An alternative method for reducing radiometric disturbance in NOAA/AVHRR data. *Photogr. Engin. Rem. Sens.*, 53, 1059-1067.

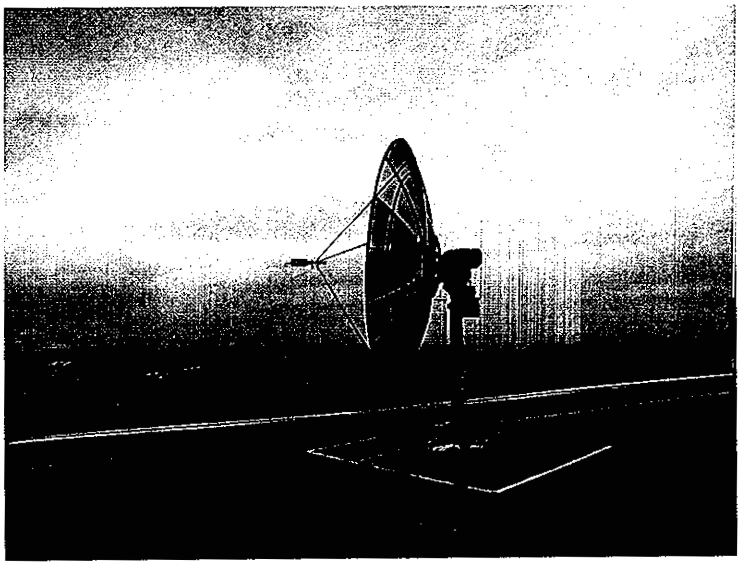
Velleman , P., and D.C. Hoaglin. 1981. *Applications, Basics, and Computing of Exploratory Data Analysis.* Duxbury Press, 343

Wilhite, D.A. 1993. Planning for Drought: A Methodology. In Drought Assessment, Management, and Planning: Theory and Case Studies (Ed. D. Wilhite), Kluwer Academic Publisher: 87-109.

Wilhite, D.A. and M.H.Glantz, 1985. Understanding the drought phenomenon: The role of definitions. *Water International*, 10: 111-120.

WMO (World Meteorological Organization), 1975. Drought and Agriculture. WMO Technical Note No. 138, WMO, Geneva, 185 pp.

APPENDIX A



Receiving stations installed at the roof of the Institute for Space Research, Academy of Sciences of Kazakhstan in Almaty.

Kazakhi team members