PN-ABY-317

isn · 98795

FINAL REPORT

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

"Estimation of seasonal dynamics of arid zone pasture and crop productivity using NOAA/AVHRR data"

Principal investigators:

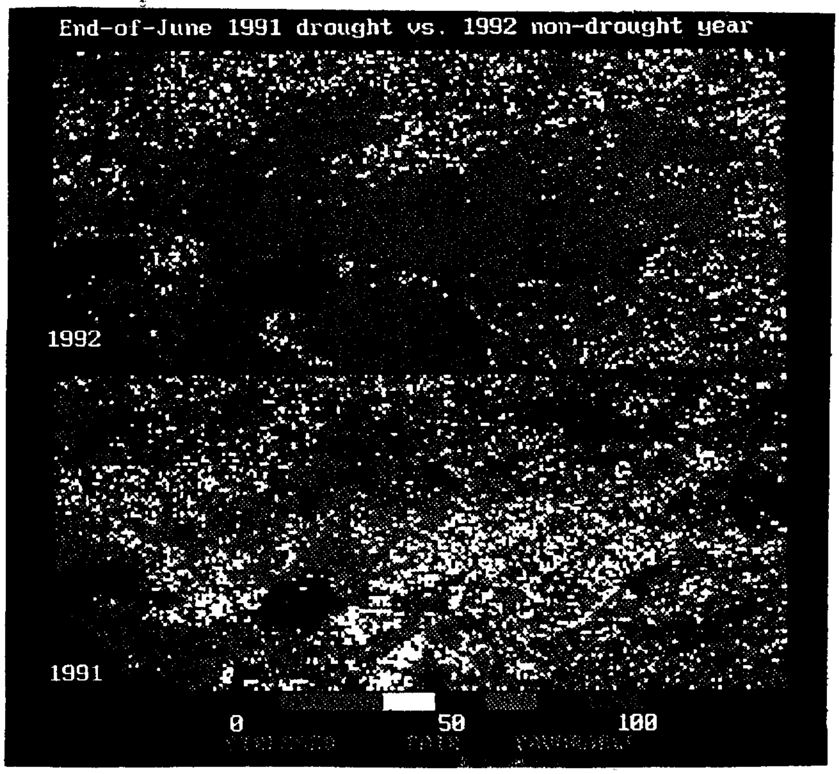
Dr. Anatoly Gitelson
J. Blaustein Institute for Desert Research, Ben-Gurion University of the Negev
Israel

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-CA13-056



List of Figures

Fig. 1. Location of weather stations and topography of Kazakhstan. Number on isoline indicate elevation in meter. Station number corresponds to the World Meteorological Organization (WMO) Standard.

Fig. 2. Location of experimental plots. A is the route of airborne radiance measurements.

Fig. 3. Weekly NDVI: smoothed (solid line) and unsmoothed (dotted line) for one 16 km x 16 km pixel (lat 39.14, long -80.86) in 1987 (Kogan, 1995a).

Fig. 4. Multi-year maximum and minimum NDVI: (a) weekly for a single pixel in the main ecological zones of K, and (b) May-August average. These data were used to estimate the contribution of the ecosystem and weather component in NDVI value, (c) vegetation zones of K (after???).

Fig. 5. NDVI and VCI dynamics at station 36819 (Almaty) in (a) 1991 (dry conditions), and (b) 1992 (favorable conditions).

Fig. 6. Relationship between NDVI and VCI for station 36819 (Almaty) in 1991.

Fig. 7. The 1994 seasonal dynamics of median NDVI value at experimental plots (100 by 100 m) of four fields (a,b,c,d) for station 36819, pasture, (A), and three fields (a,b,c) for station 36874, spring barley (B) in Almaty region. Median value for each plot were derived from at least 20 random measurements of reflectance over space.

Fig. 8. Seasonal dynamics of median NDVI value and standard deviation of NDVI for all plots shown in Fig. 7a in 1994 for station 36819 (Almaty region). These values were derived from four pasture plots.

Fig. 9. Spatial variation of NDVI along 20 km transect through pasture fields (c) and (d) at station 36819 (Almaty) measured by photometer DPF on board of helicopter on August 12, 1994.

Fig. 10. Averaged NDVI for 3 by 3 of 16 km resolution pixels calculated from NOAA-11 polar-orbiting satellite and median NDVI retrieved from hand-held radiometer measurements shown in Fig. 8.

Fig. 11. Seasonal dynamics of biomass measured at experimental plots (100 by 100 m) of four fields (a,b,c,d) for station 36819, pasture, (A), and three fields (a,b,c) for station 36874, spring barley (B) in Almaty region in 1994. For each plot biomass biomass was derived as average from four measurements.

Fig. 12. NDVI versus biomass for four pasture plots of station 36819 in 1994. (A) NDVI was derived from hand-held radiometer measurements, and biomass was averaged from four measurements at each plot; (B) median NDVI and median biomass calculated for four plots of fields (a,b,c,d).

Fig. 13. Median NDVI versus median biomass for three spring barley plots of station 36874 in 1994. (A) NDVI was derived from hand-held radiometer measurements, and biomass was averaged from four measurements at each plot; (B) median NDVI and median biomass calculated for four plots of fields (a,b,c,d).

Fig. 14. Seasonal dynamics of density deviation (DD) from multi-year minimum (A) and median (B) values, normalized to the 1985-1993 density fluctuation (D_{max}-D_{min}). Almaty region, station 36819.
Fig. 15. Comparison of the VCI and multi-year density deviation (A) from minimal, and (B) median. Almaty region, station 36819, 1991.
Fig. 16. Comparison of the VCI and multi-year density deviation (A) from minimal, and (B) median. Almaty region, station 36819, 1992.
Fig. 17. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Almaty region, station 36744.
Fig. 18. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Akmola region, station 28978.
Fig. 19. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Akmola region, station 35376.
Fig. 20. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Jeskazgan region, station 35884.
Fig. 21. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Jeskazgan region, station 35478.
Fig. 22. Correlation between the VCI and median-derived density deviation for Almaty 36819 (A) and 35744 (B).
Fig. 23. Correlation between the VCI and median-derived density deviation for Akmola 35376 (A) and 28978 (B).
Fig. 24. Correlation between the VCI and median-derived density deviation for Jeskazgan 35478 (A) and 35884 (B).
Fig. 25. Correlation between the VCI and median-derived density deviation for all six stations and two years (1991 and 1992).
Fig. 26. Vegetation Condition Index for the end of June (week 26) 1991 and 1992 for each 16x16 km pixel.
Fig. 27. Vegetation Condition Index for the beginning of July (week 27) 1991 and 1992 for each 16x16 km pixel.
Fig. 28. Vegetation Condition Index for the beginning of May (week 18) 1991 and 1992 for each 16x16 km pixel.
Fig. 29. Vegetation Condition Index for week 22 from the end of May through the beginning of June 1991 and 1992 for each 16x16 km pixel.
Fig. 30. Vegetation Condition Index for the end of August (week 35) 1991 and 1992 for each 16x16 km pixel.
Fig. 31. Vegetation Condition Index for May 1-7 (week 18) 1995 for each 16x16 km pixel.
Fig. 32. Vegetation Condition Index for May 29-June 4 (week 22) 1995 for each 16x16 km pixel.
Fig. 33. Vegetation Condition Index for June 26-July 4 (week 26) 1995 for each 16x16 km pixel.

List of Tables

II. Table of Contents

III. **Executive Summary**

Most of Kazakhstan's pasture and crop land 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

As the result of this project, we developed

scientific principles, hardware and software background of a non-conventional system that will use NOAA operational polar-orbiting satellites for quantitative assessments of pasture/crop conditions and productivity in Kazakhstan.

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 IBM 486 for data collection and initial processing;

* image processing hardware and software for data processing, storage and distribution;

* algorithms for converting satellite radiances into a new Vegetation Condition Index (VCI);

* algorithms for converting the VCI 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 results of this research will be used to improve monitoring of the environment, especially those conditions and phenomena that have an unfavorable impact on pasture and crop productivity. These results will also help to increase the accuracy of agricultural production estimates and provide better spatial and temporal coverage. Such improvements, in turn, will help 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 will 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 will help Kazakhstan to start using new remote sensing technology for drought monitoring. The delivered hardware, software, and proposed concept and methods, will provide a basis for a new, complete and efficient drought-watch system. This system will be 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 will also help 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 will be, 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 Kazakhstani Government.

All project goals were achieved. Scientific principles, hardware and software of the non-conventional system which will use NOAA operational polar-orbiting satellites for quantitative assessments of pasture and crop conditions and productivity in K were developed. In addition, several other important tasks were accomplished:

* calibration of satellite-derived indices versus ground data at experimental sites;
* remote aircraft measurements together with ground observations;
* near real-time monitoring drought and vegetation conditions in 1995.

Future work should include:

- * launching a system for receiving satellite images and real-time monitoring of drought, and monitoring of crop and pasture conditions and their productivity;
- * developing satellite data base for the entire Kazakhstan.
- * calibrating and validating the algorithms for major crop- and pasture-producing regions of Kazakhstan.

4. Research objectives and innovative aspects

4.1 Introduction

Kazakhstan occupies 2,717,000 km^2 of territory, which is equivalent to almost one third of the United States of America. The economy of Kazakhstan is highly dependent on agriculture, which has grain and livestock production orientation. In recent years, grain crops were produced on an area 23 to 25 million hectares, while 200 million hectares of grass lands provided the main source for feed.

Agricultural production is highly dependent on climate and weather. Most of Kazakhstan's crop and pasture land is located in arid and semi-arid zones with a limited amount of precipitation. Fluctuations of rainfall during the growing season from year to year are large and put severe additional constraints on agriculture, because farmers have to cope with water deficit. Drought is the most typical phenomenon of the Kazakhstani climate, occurring every two to four years. Intensive droughts were observed in 1989, 1991 and 1993, causing variation in total grain production from 12 (1991) to 30 (1992) million metric tons. Droughts in Kazakhstan are often accompanied by dessicative wind and sometimes continue for several consecutive years.

In order to mitigate these harsh climatic and weather conditions, efficient management of water resources, and advanced estimation and planning of agricultural production and pasture conditions are required. Fulfillment of these tasks is impossible without thorough monitoring of crop environment and conditions, assessment of weather impacts, and estimation of large scale crop and pasture production. Also drought detection and monitoring of its expansion, duration, and impact are very important tasks.

At presents 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 et al., 1986; Townshend et al., 1986; Tucker et al., 1986; Justice et al., 1986; Rao et al., 1990; Ohring et al., 1989; and NOAA, 1989, 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 provides answers to all of these problems.

4.2 Objectives

The overall goal of this project was to develop

> *scientific principles, algorithms, hardware and software for a non-conventional system that will use NOAA operational polar-orbiting satellites for quantitative assessments of pasture and crop conditions and productivity in Kazakhstan.*

The system includes:

* The High Resolution Picture Transmission (HRPT) satellite receiving station with tracking antenna and positioner and receiver/demodulator/sectorizing subsystems;

* on-line PC for data collection and initial processing;

* image processing hardware and software for data processing, storage and distribution;

* development of a new Vegetation Condition Index (VCI);

* algorithms for converting the VCI into ground-derived environmental and agricultural characteristics.

Specific tasks included:

* development and implementation of algorithms for using data observed with the Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA polar orbiting satellites for monitoring seasonal dynamics of arid zone pasture and crop conditions and production, as well as and also crop and pasture environments.

* quantitative estimation of pasture and crop conditions and yield;

* assessment of seasonal dynamics of pasture and crop productivity for major ecological zones of Kazakhstan;

* development of algorithms for drought detection and the monitoring of drought development, extent, duration, and impact on vegetation on a large area;

* development of remote sensing and ground-truth PC data bases for efficient use and distribution;

* transferring new remote sensing technologies and skills in using operational satellite data for sustainable agricultural development in Kazakhstan.

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 will promote 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 will extend 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 ground-truth data collection and 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

First time

* satellite operational technologies were applied to
    - estimation of crop and pasture conditions and productivity over a large area with different ecological and climatic zones;
    - drought detection and monitoring in an area of extreme continental climate.

* algorithms were developed for quantitative assessment of crop and pasture productivity;

* the developed algorithms were validated against ground measurements collected by conventional and remote sensing techniques over a large area of Kazakhstan.

5. Methods and Results

5.1 Rational

5.1.1 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.

5.1.2 The Normalized Difference Vegetation Index

The concept of the vegetation index is based on green vegetation's differential reflection radiance in the visible (0.58-0.68 channel 1 or Ch1) and near infrared (0.725-1.10 channel 2 or Ch2) wavelength. Spectral measurements in these channels are responsive to the chlorophyll content, and to the structure of the mesophyll and corresponding water content in leaves (Tucker and Sellers, 1986). These physiological properties determine low spectral reflectance in Ch1 and high reflectance in Ch2. The difference between the bands was found to relate to such properties of vegetation as leaf area index, photosynthetic capacity, and biomass (Sellers, 1985) and through time to the vegetation environment (Goward et al., 1985). This difference is usually normalized and named the Normalized Difference Vegetation Index (NDVI) which has the following expression:

$$\mathrm{NDVI} = (\mathrm{Ch2}-\mathrm{Ch1})/(\mathrm{Ch2}+\mathrm{Ch1})$$

Extensive applications of NDVI data for global vegetation mapping have been demonstrated in many publications (e.g., Tucker et al., 1985; Malingreau, 1986; Townhsend et al., 1986; Prince et al., 1986; Justice et al., 1986; Ohring et al., 1989). Recently, a new algorithm has been developed that offers new opportunities for monitoring climate and land surface parameters and phenomena. This algorithm was verified and shown to be useful for monitoring drought, weather impacts, vegetation conditions, soil moisture, and productivity of ecosystem and agricultural crops (Kogan, 1987, 1990, 1995; Kunkel et al., 1991).

However, by the very nature of remotely sensed data, satellite-derived environmental measurements are indirect and require calibration and validation by actual ground observations. The application of the developed algorithms to new areas requires the verification of these algorithms against ground measurements and in most cases modification and adjustment of these algorithms to the environmental geographic and economic conditions; parametrization of the models' coefficients is also needed.

5.2 Data description

Two data sets were applied in this study: remote sensing data obtained from NOAA polar-orbiting operational satellites and conventional (actual or "ground-truth") data obtained from weather station observations, measurements of vegetation characteristics and radiances in field experiments.

5.2.1 Satellite data

These data were collected from the Global Vegetation Index (GVI) data set that is produced by NOAA's National Environmental Satellite Data and Information Service (NESDIS), described in Tarpley et al. (1984) and Kidwell (1990). The GVI is produced by sampling and mapping the 1- km daily radiance, measured by the Advanced Very High Resolution Radiometer (AVHRR) on board NOAA polar orbiting satellites, to a 16 km map. Radiances measured in the visible and near infrared wavelengths are used to calculate the NDVI.

The daily maps of GVI parameters (radiance, NDVI, satellites and sun angles) are integrated over a seven-day period by saving those values that have the largest difference between radiance for the near infrared and visible wavebands during the seven days for each map cell. This procedure has the effect of minimizing cloud contamination in the weekly composite. The weekly GVI data from April 1985 through 1995 were used in this project.

5.2.2. Ground measurements

Ground measurements were collected from weather station observations and measurements in field experiments.

Weather observations were obtained from 69 stations during the 1985-1994 period. The locations of the stations are shown in Fig. 1 and Table 1. Weather observations included 10-day total precipitation (mm) and average temperature (^{o}C), end of 10-day soil moisture (mm), phenology and density of vegetation (number of plants per square meter).

During the growing seasons of 1994 and 1995, 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). The locations of these plots are shown in Fig. 2. 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.

An airborne radiometer (two channels field photometer DPF, designed by the Institute for Experimental Meteorology, Russia) was used to measure the radiance in the same Ch1 and Ch2 spectral bands as the AVHRR sensor. These measurements were carried out once from a MI-4 helicopter along route A shown in Fig. 2.

5.3 Algorithm development

A fundamental constraint to the application of satellite-derived NDVI for vegetation monitoring is the presence of considerable noise which is comparable to the estimated environmental signal. The largest noise comes from fluctuating transparency of the atmosphere, especially the presence of clouds and aerosols. The other major causes of instability are changing sun and sensor geometry, bi-directional reflectance of the atmosphere and surface, satellite orbital drift, uncertainty in the sensor calibration, and methods of sampling, calculating and mapping of these data (Gutman, 1991; Goward et al., 1991). To minimize cloud effect, the temporal compositing procedure (integration over 7 days) is currently used. However, this procedure creates some other noise in GVI data. As the result, the seasonal curve of the NDVI is very erratic (Fig. 3). These fluctuations must be removed from the data before their application. In addition, NDVI values

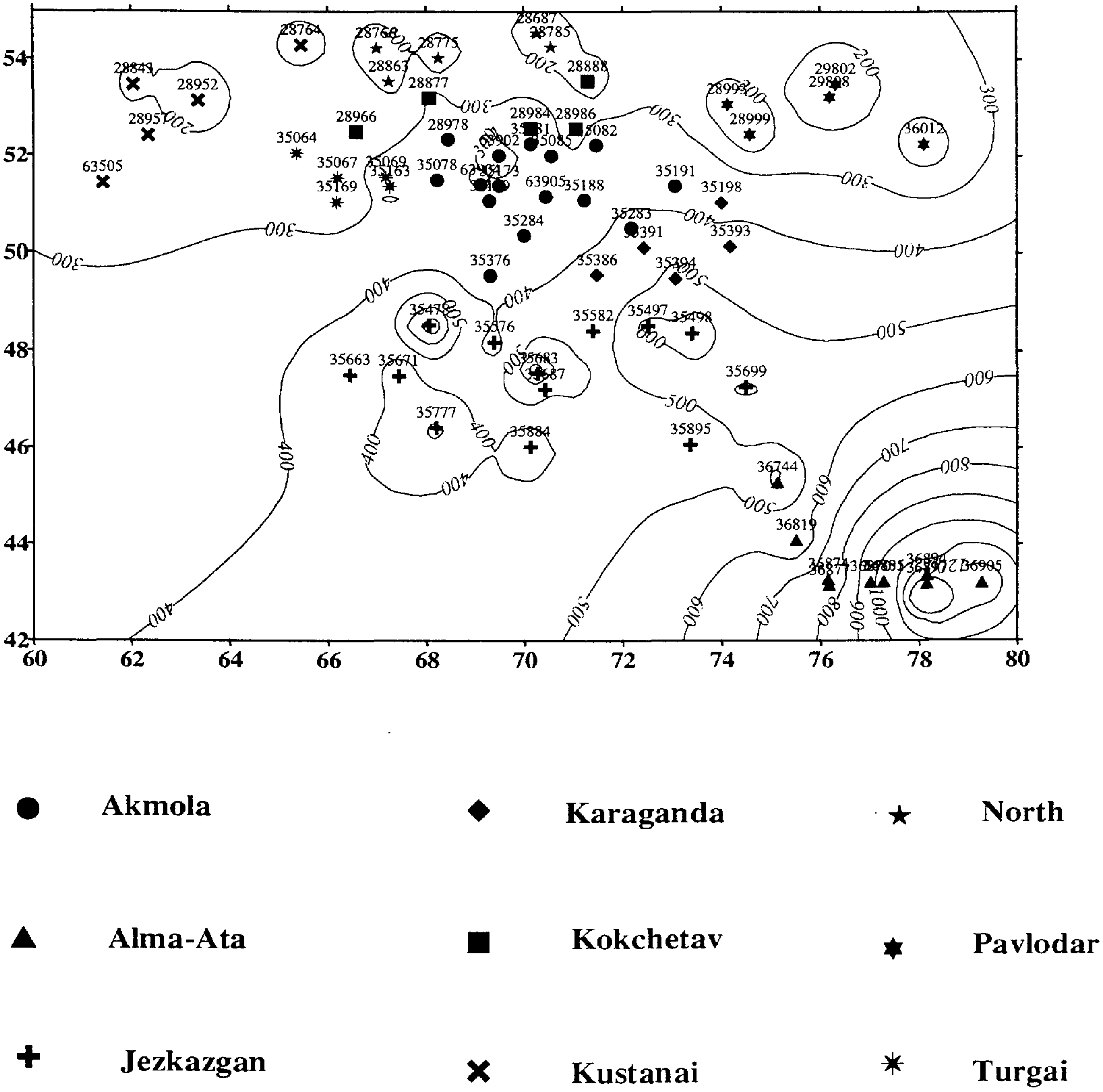


Fig. 1. Location of weather stations and topography of Kazakhstan. Numbers on isoline indicate elevation in meters. Station number corresponds to the World Meteorological Organization (WMO) Standard.

Table 1. WMO Station number,coordinates and the name of Kazakhstan regions (oblast).

AKMOLA

N Station	Latitude	Longitude	Height
28978	52.32	68.45	399
35078	51.49	68.22	308
35081	52.24	70.14	332
35082	52.21	71.48	397
35085	52.00	70.57	384
35173	51.37	69.50	305
35179	51.06	69.30	324
35188	51.08	71.22	348
35191	51.37	73.08	397
35283	50.50	72.18	426
35284	50.35	70.00	331
35376	49.53	69.31	350
63902	52.00	69.50	214
63904	51.39	69.11	283
63905	51.16	70.44	322

ALMATY

N Station	Latitude	Longitude	Height
36744	45.28	75.13	362
36819	44.08	75.51	498
36870	43.21	77.01	847
36874	43.27	76.16	643
36877	43.14	76.18	814
36885	43.22	77.28	1098
36894	43.36	78.15	606
36897	43.18	78.15	2216
36905	43.20	79.28	1273
64801	43.22	77.28	1091

Table 1 (cont.)

JESKAZGAN

N Station	Latitude	Longitude	Height
35478	48.52	68.06	790
35497	48.51	72.52	656
35498	48.37	73.41	724
35576	48.18	69.39	361
35582	48.41	71.40	488
35663	47.50	66.45	505
35671	47.48	67.43	350
35683	47.54	70.28	796
35687	47.21	70.42	471
35699	47.27	74.49	619
35777	46.41	68.20	276
35884	46.02	70.12	328
35895	46.07	73.37	400

KARAGANDA

N Station	Latitude	Longitude	Height
35198	51.03	74.00	372
35386	49.55	71.48	422
35391	50.11	72.43	420
35393	50.13	74.18	450
35394	49.48	73.08	555

KOKCHETAV

N Station	Latitude	Longitude	Height
28877	53.19	68.06	319
28888	53.55	71.30	101
28966	52.49	66.58	227
28984	52.57	70.13	398
28986	52.56	71.05	196

KUSTANAI

N Station	Latitude	Longitude	Height
28764	54.29	65.47	161
28843	53.47	62.06	187
28952	53.13	63.37	121
28957	52.41	62.36	208
63505	51.42	61.42	262

NORTH

N Station	Latitude	Longitude	Height
28687	54.54	70.27	134
28766	54.22	67.00	153
28775	54.02	68.26	115
28785	54.26	70.55	127
28863	53.53	67.25	150

PAVLODAR

N Station	Latitude	Longitude	Height
28993	53.07	74.12	126
28999	52.44	74.58	115
29808	53.22	76.19	118
29802	53.49	76.32	114
36012	52.24	78.10	149

TURGAI

N Station	Latitude	Longitude	Height
35064	52.04	65.37	252
35067	51.53	66.20	222
35069	51.54	67.18	386
35163	51.36	67.26	261
35169	51.03	66.18	267

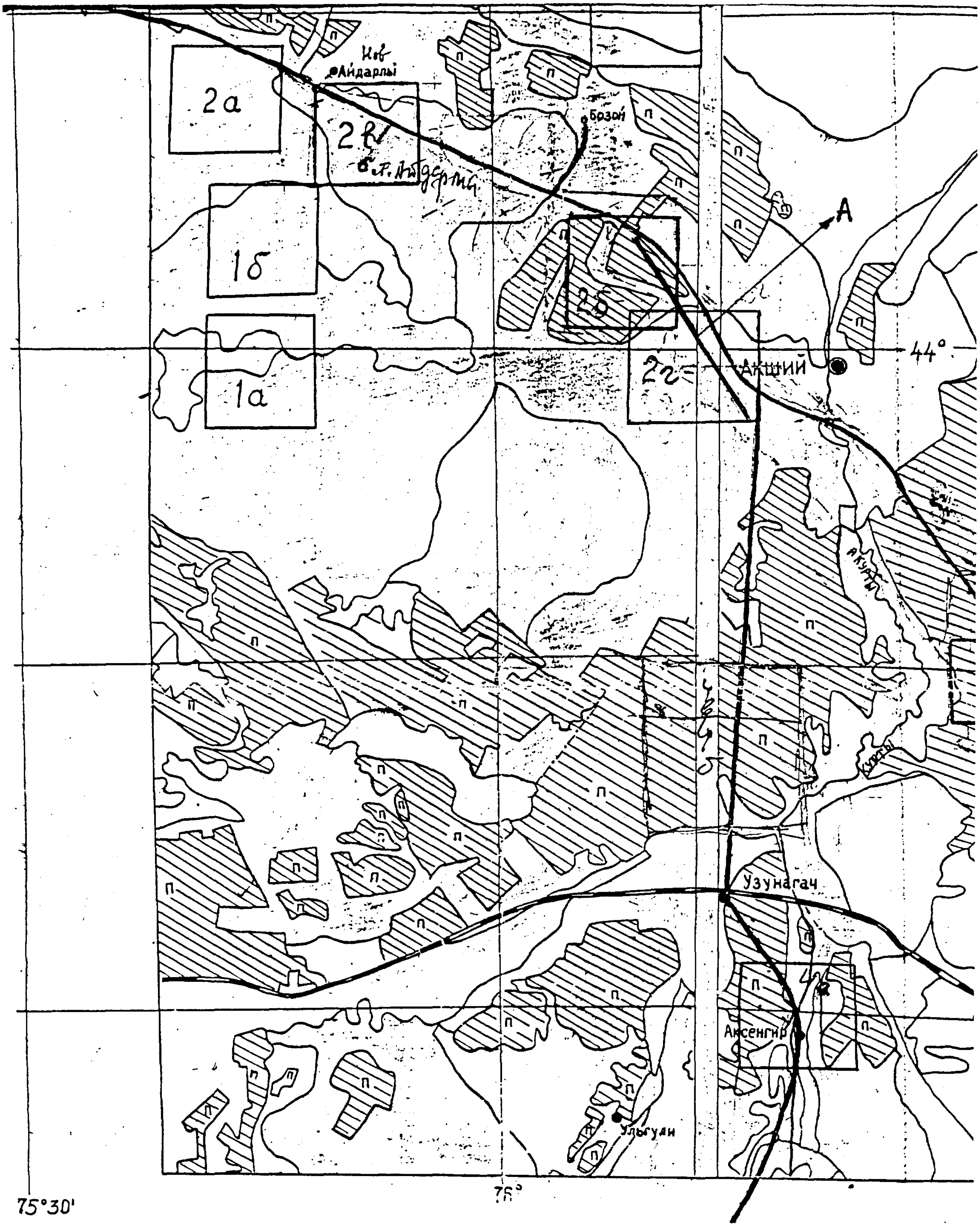


Fig. 2. Location of experimental plots. A is the route of airborne radiance measurements.

reflect the combine influence of ecology and weather on vegetation. Moreover, the weather signal in the NDVI value is much weaker than the ecological one. That is why the weather signal is not easily detectable (Kogan, 1987; 1990). Since the objectives of this proposal required estimation of weather-related NDVI, this portion of the NDVI must be separated from the total NDVI value.

5.3.1 Principles of the algorithm

An algorithm was designed to reduce noise and to enhance the weather-related component in time series of NDVI data. Since complete physically-based corrections for all atmospheric effects and for various land surfaces are not available, temporal fluctuations were removed by smoothing the weekly NDVI time series with a compound median filter (Velleman et al. 1981). This technique was superior to others in eliminating outliers, emphasizing the annual vegetation cycle and weather-related NDVI fluctuations (van Dijk et al. 1987; Kogan 1987, 1990). The smoothed curve in Fig. 3 illustrates this superiority.

After smoothing year-to-year, differences caused by weather variations in NDVI became more apparent (Fig. 2 in Kogan, 1995a). Following this approach, the NDVI quantifies both spatial differences between productivity of ecosystems (ecosystem component) and year-to-year variations in each ecosystem due to weather fluctuations (weather component). The ecosystem component is mainly controlled by such slow changing environmental factors as climate, soil, topography, and vegetation type that determine the amount and distribution of vegetation on the Earth. The weather component of NDVI is controlled by weather parameters (rainfall, temperature, wind, etc.) which determine vegetation state and greenness during the annual cycle.

The weather component of NDVI is superimposed on the ecosystem component. Maximum amount of vegetation is developed in years with optimal weather since such weather stimulates efficient use of ecosystem resources (for example, increase in the rate of soil nutrition uptake). By contrast, minimum vegetation is developed in years with extremely unfavorable weather conditions (mostly dry) which suppress vegetation growth directly and indirectly through a reduction in the rate of ecosystem resources use. For example, lack of water in drought years reduces considerably the amount of soil nutrition uptake. The absolute maximum and minimum of NDVI calculated from several years of data that contain extreme weather events can be used as criteria for quantifying these extreme conditions.

In this project, we calculated the highest and the lowest NDVI values during 1985-1993 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 Kazakhstan's ecosystems. Since the minimum and maximum NDVI curves delineate the contribution of ecosystem component in the NDVI value for the cases with the

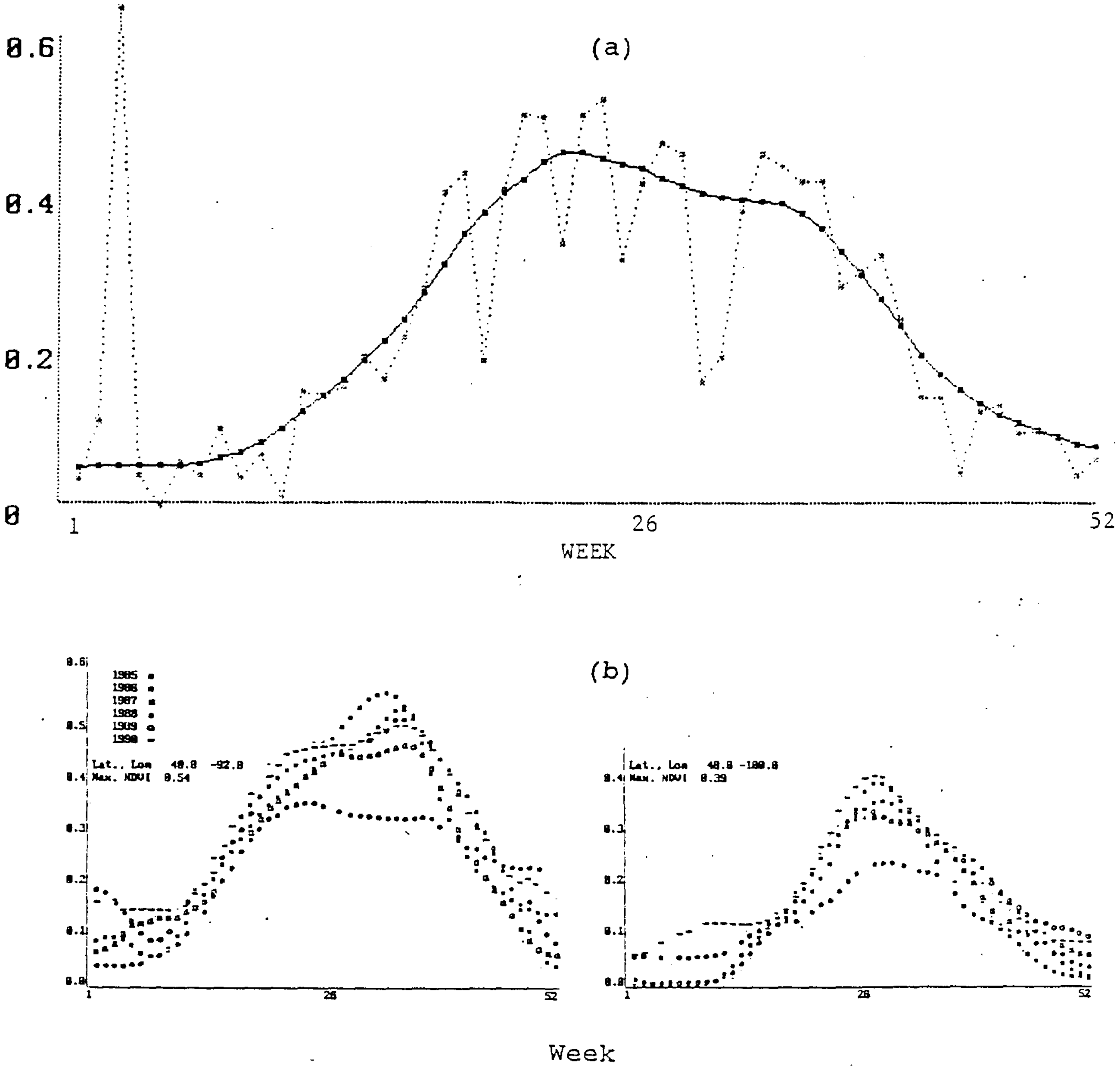


Fig. 3. Weekly NDVI: smoothed (solid line) and unsmoothed (dotted line) for one 16 km x 16 km pixel (lat 39.14, long -80.86) in 1987 (Kogan, 1995a).

most extreme weather, the area between these curves largely approximates the weather-driven component of the NDVI .

Figure 4 shows the weekly maximum and minimum NDVI curves for selected ecosystems (one pixel for the ecosystem) typical for Kazakhstan. Each ecosystem has its own NDVI signature in terms of NDVI value, shape of the curve, rate of NDVI change during leaf appearance and senescence, and partitioning of NDVI value into weather and ecosystem components. The northern Kazakhstan has the highest NDVI values with clearly defined seasonal dynamics and smaller total area of weather (blue envelope) versus ecosystem components (green area). This type of seasonal dynamics is typical for Kazakhstan steppe zone with 400 to 500 mm of annual precipitation. Moving to the south, the NDVI decreases, does not show distinctive seasonal dynamics, and has an almost equal contribution of weather and ecosystem components into the integrated area under the maximum curve. This represents Kazakhstan's semi-arid and desert climate.

Figure 4b shows stratification of the whole Kazakhstan area (for each 16 km by 16 km grid) based on the maximum and minimum NDVI averaged for the middle of the growing season (May through August). It should be noted that nine years of data hardly satisfy statistical requirements to formulate reliable conclusions. However, the concept of the minimum NDVI suggests the existence at least one year in the study period with drought such as 1991 in Kazakhstan. For near-optimal weather several years of data were used. Verification showed that even for such a small sample there is a very good correspondence between spatial distribution of NDVI-derived zones in Fig. 4b and spatial distribution of vegetation and climate zones based on *in-situ* data.

5.3.2 Vegetation Condition Index

For vegetated regions the integrated area of the weather-related NDVI component is smaller than the ecosystem one. Consequently, the weather impacts on vegetation are not easily detectable from NDVI data. When the NDVI was used for assessment of these impacts and drought detection, the weather component of the NDVI was enhanced by separating it from the ecosystem component (Kogan 1987, 1990, 1995a). Therefore, the weather-related NDVI envelope (blue area in Fig. 4a) was linearly scaled from zero, minimum NDVI to 100, maximum NDVI for each grid cell and week. The resulting parameter was named the Vegetation Condition Index (VCI) defined by the following expression:

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

where NDVI, $NDVI_{max}$, and $NDVI_{min}$ are the smoothed weekly Normalized Difference Vegetation Index, its multi-year maximum, and multi-year minimum, respectively, calculated for each pixel.

(A)

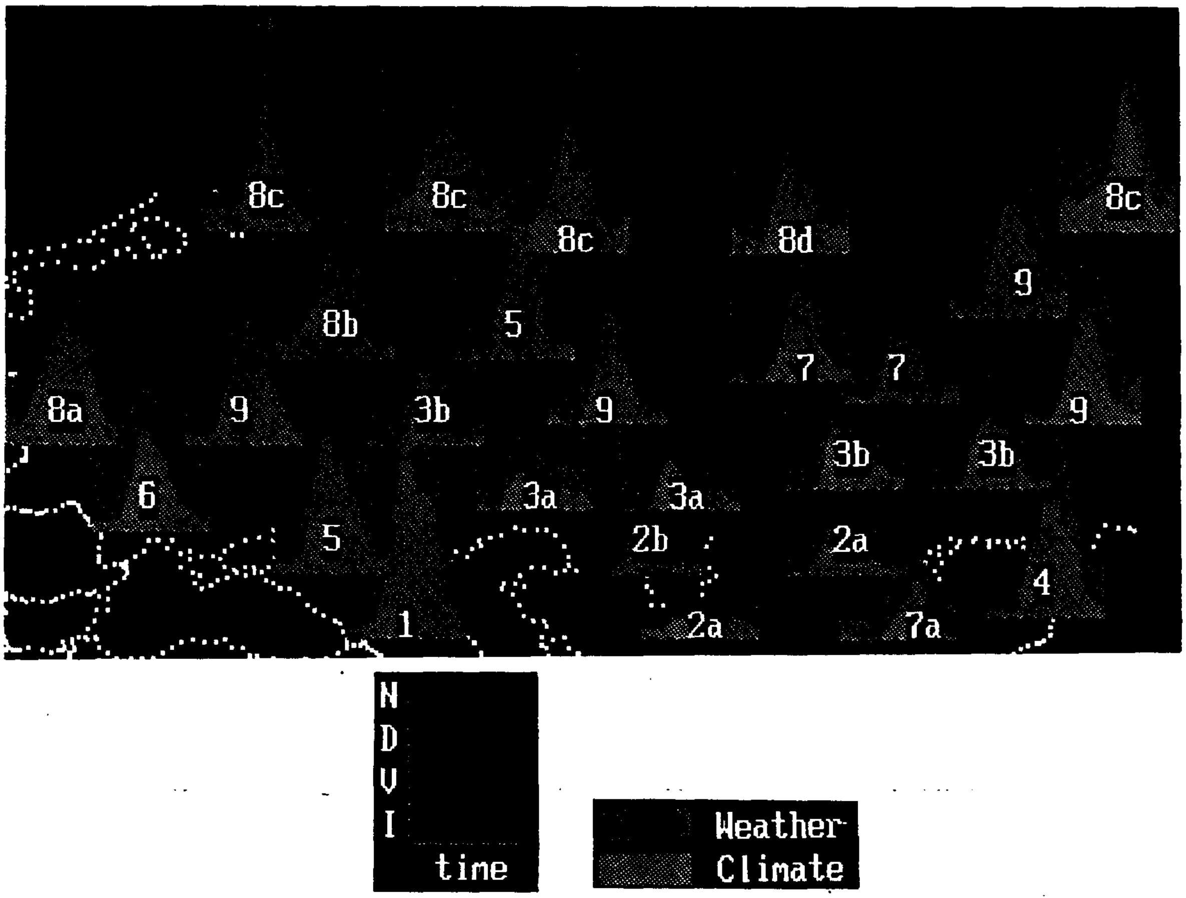


Fig. 4. Multiyear maximum and minimum NDVI: (A) weekly for a single pixel in the main ecological zones of the former Soviet Union, including Kazakhstan (the southeast quadrant), and (B) May-August average. These data were used to estimate the contribution of the ecosystem and weather component in NDVI value. The NDVI time series in (A) are shown for the ecological zones (Atlas of the USSR's Agriculture, 1960): 1) broadleaf forest of Caucasus, annual precipitation 1200-1600 mm; 2) desert, less then 150 mm (a) shrubs and saxaul, (b) wormwood and saline; 3) semi-desert (a) southern, 150-200, (b) northern, 200-250 mm; 4) mountain alpine meadow; 5) flood meadow; 6) steppe, chernozem soil, 500 mm; 7) steppe, chestnut soil, 250-350 mm; 8) forest (a) broadleaf, 600-700 mm, (b) dark coniferous, 500-600, (c) pine, 500-600 mm, (d) mid-taiga dark coniferous, 400 mm; 9) prairie.

(B)

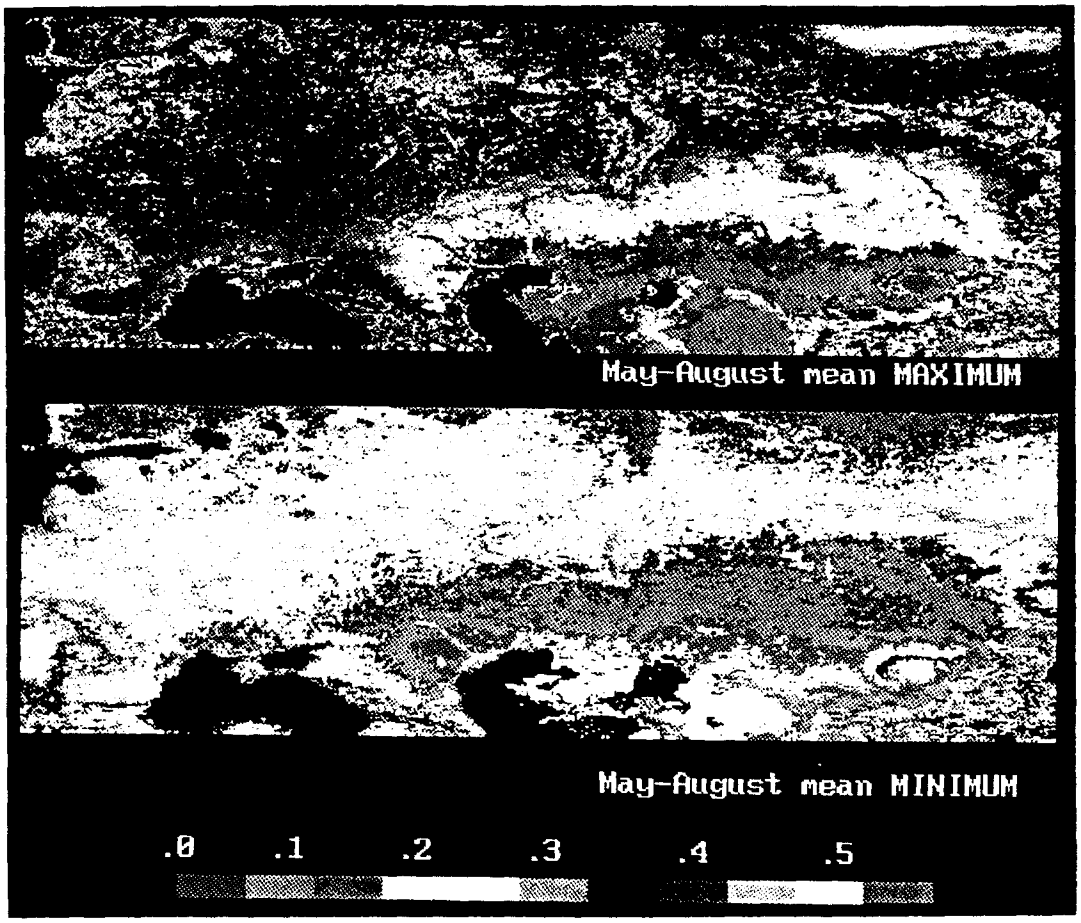


Fig. 4.

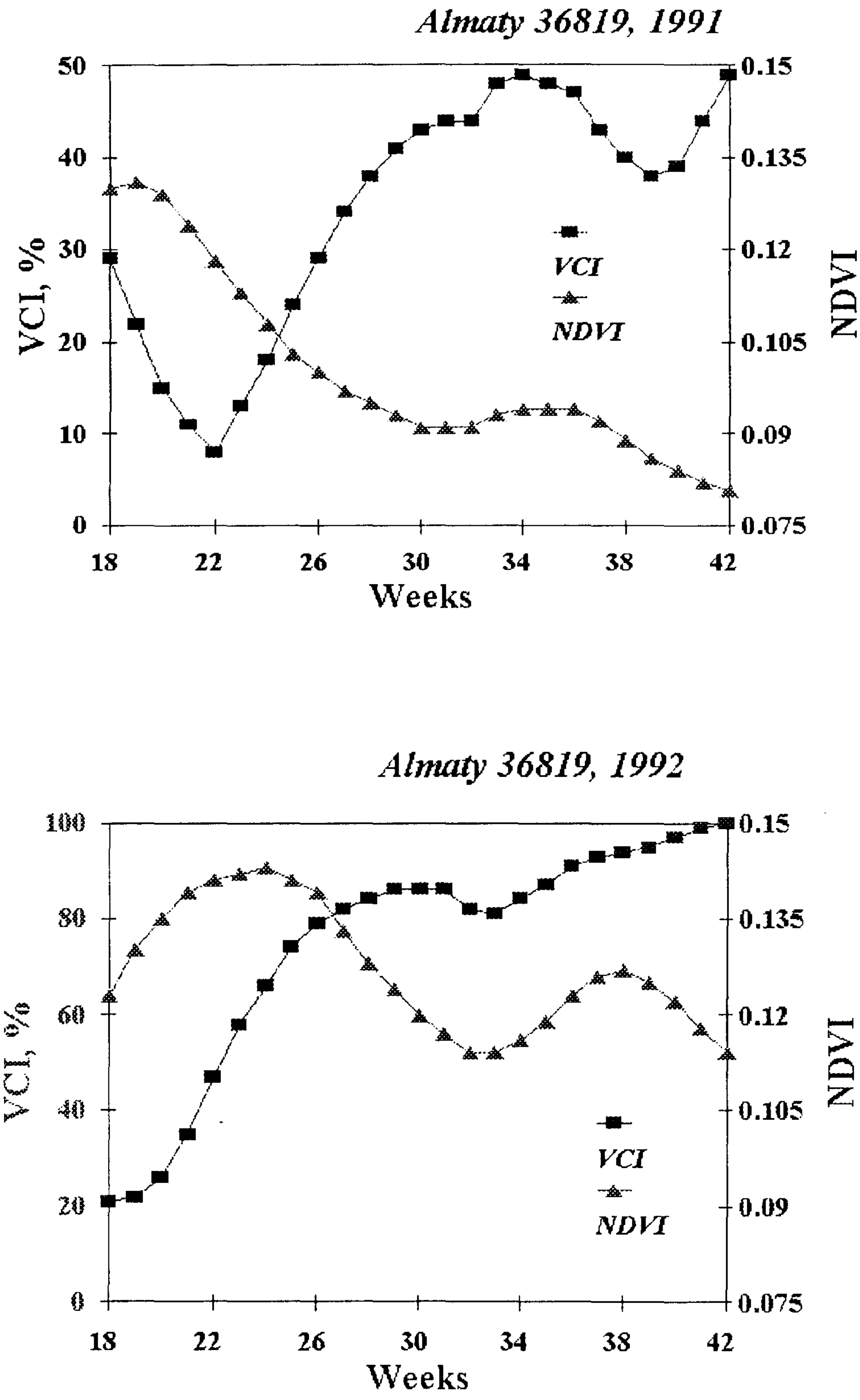


Fig. 5. NDVI and VCI dynamics at station 36819 (Almaty) in (a) 1991(dry conditions), and (b) 1992 (favorable conditions).

The VCI approximates the weather-related component in the NDVI value. It changes from zero to 100, corresponding to the changes in vegetation conditions from extremely unfavorable to optimal. We should note that NDVI can also be used for estimation of vegetation conditions but only for one location. If we need to compare the vegetation state in different ecological and climatic zones, the VCI will provide more accurate estimates. Figure 5 shows NDVI and VCI dynamics on one of the test sites in Kazakhstan during two years with extremely different weather conditions. Although NDVI had very similar dynamics during these years, the VCI indicates that the dynamics of vegetation conditions were very different and VCI values in 1992 were two to three times larger than in 1991. The difference between the NDVI and VCI is clearly demonstrated by Fig. 6. This relationship indicates that the same VCI value corresponds to several different NDVI values: two for weeks 10 to 30 and even three for weeks 44 to 48.

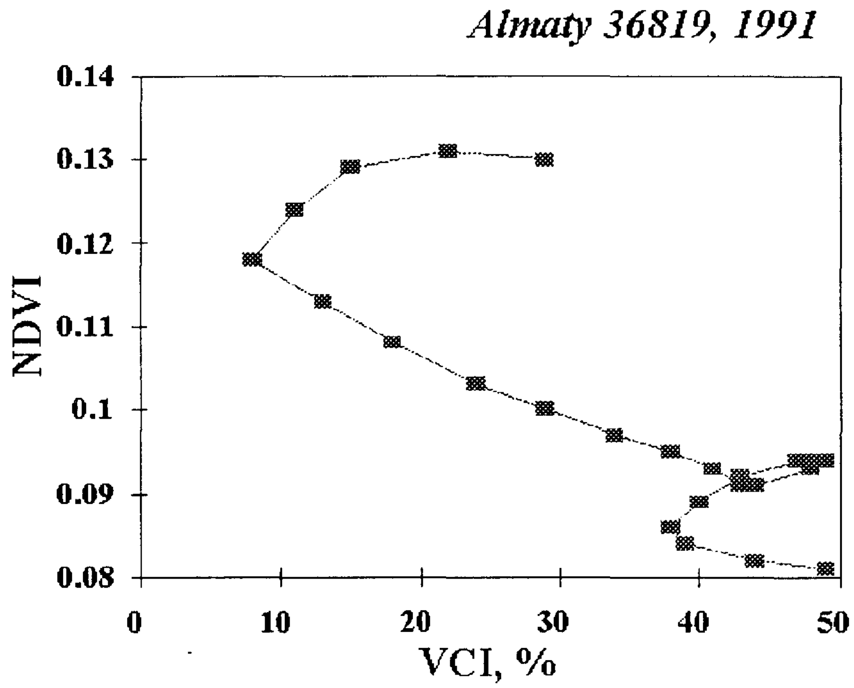


Fig. 6. Relationship between NDVI and VCI for station 36819 (Almaty) in 1991.

The VCI application for drought analysis was investigated in our earlier publications. VCI values appropriate for drought detection and monitoring were determined by correlating US crop yield with VCI (Kogan 1995a, b). The 20 percent yield reduction during drought years was associated with 0 to 35 of VCI. This range was accepted as a VCI-derived drought indicator. In order to use the VCI as a tool for assessment of vegetation conditions it should be calibrated against some weather-dependent characteristics of vegetation, such as vegetation height, density, biomass, and yield of pasture and crops. Therefore, the largest part of this project was devoted to collecting the above-mentioned vegetation characteristics.

5.4 Results of the 1994 ground measurements at test sites in Kazakhstan

Since satellite measurements relate to large, non-uniform areas we investigated first, spatial and seasonal variations of NDVI, measured by a hand-held radiometer, and, second, compared them with ground measurements of vegetation biomass, which also shows non-homogeneous behavior.

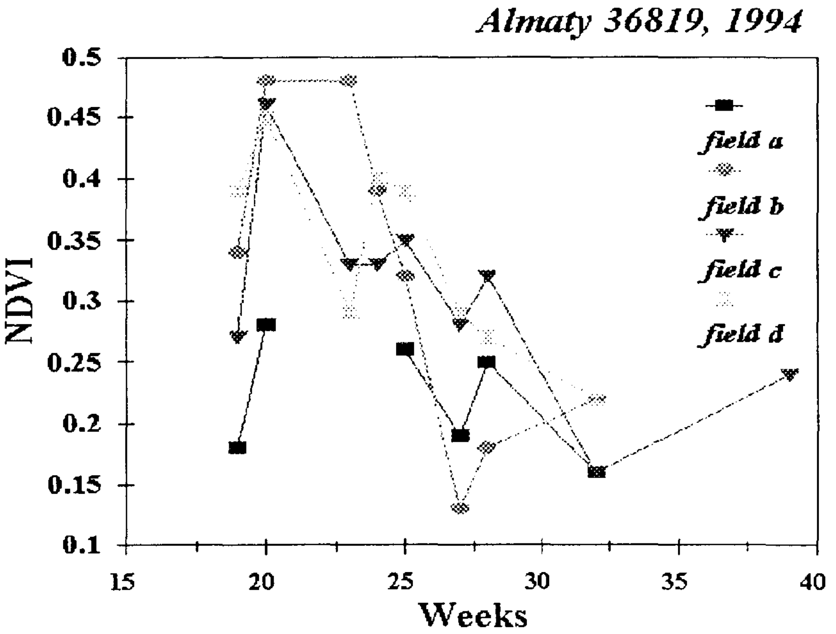
5.4.1 Spatial variation of NDVI

Figure 7 shows the spatial variation of NDVI during the growing season for grassland (a) and spring barley (b). Each plot had size 100x100 m. Both vegetation types showed clear seasonal dynamics of NDVI with a maximum being reached from the end of May through June. The maximum of NDVI over the barley plot (b) occurred later due to late planting. This indicates that in addition to the natural spatial variability NDVI values also characterize spatial variability, due to agricultural technology. As seen from the coefficient of variation (Fig. 8), natural spatial variability of NDVI can reach as much as 30 %.

It can be larger if technological changes contribute to this variability as indicated in Fig. 7b (plot b).

Spatial variation of NDVI was also measured by photometer on board a helicopter along the 20-km transect of pasture fields (c) and (d) on August 12, 1994. As can be seen, the one-time measured spatial variation was extremely large for each of these fields and, particularly between the fields (19 % and 35 %). Extreme NDVI values changed from 0.11 to 0.22 for field (d) and from 0.05 to 0.017 for field (c), and, what was the most important, from 0.05 to 0.22 between the fields. This clearly indicates that spatial non-uniformity of earth surface plays a very important role and should not be overlooked when NDVI is used to calibrate environmental and agricultural characteristics. It also indicates that the NDVI should not be interpolated over space even if it is used for large-scale climatic, ecological, and agricultural monitoring.

Since the atmosphere distorts satellite-derived radiance and calculated NDVI, we also investigated its dynamics against NDVI measured on the ground. The 1994 NDVI dynamics derived from the NOAA-11 polar-orbiting satellite were matched with NDVI dynamics derived from a hand-held radiometer (Fig. 10). Unfortunately, the period of this comparison is short because we did not have ground measurements prior to week 19, and satellite measurements were



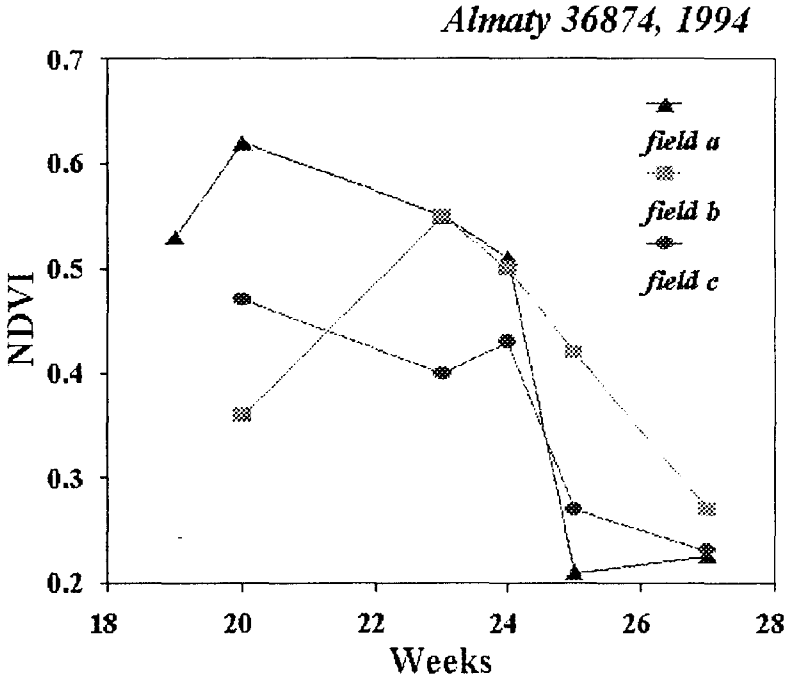


Fig. 7. The 1994 seasonal dynamics of median NDVI values at experimental plots (100 by 100 m) of four fields (a,b,c,d) for station 36819, pasture, (A), and three fields (a,b,c) for station 36874, spring barley (B) in the Almaty region. Median values for each plot were derived from at least 20 random measurements of reflectance over space.

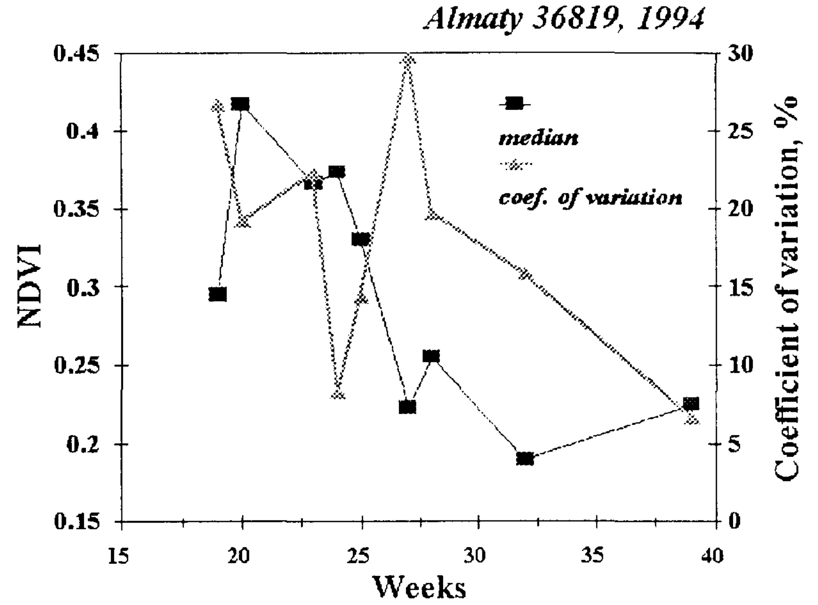


Fig. 8. Seasonal dynamics of median NDVI values and its coefficient of variation for all plots shown in Fig. 7a in 1994 for station 36819 (Almaty region). These values were derived from four pasture plots.

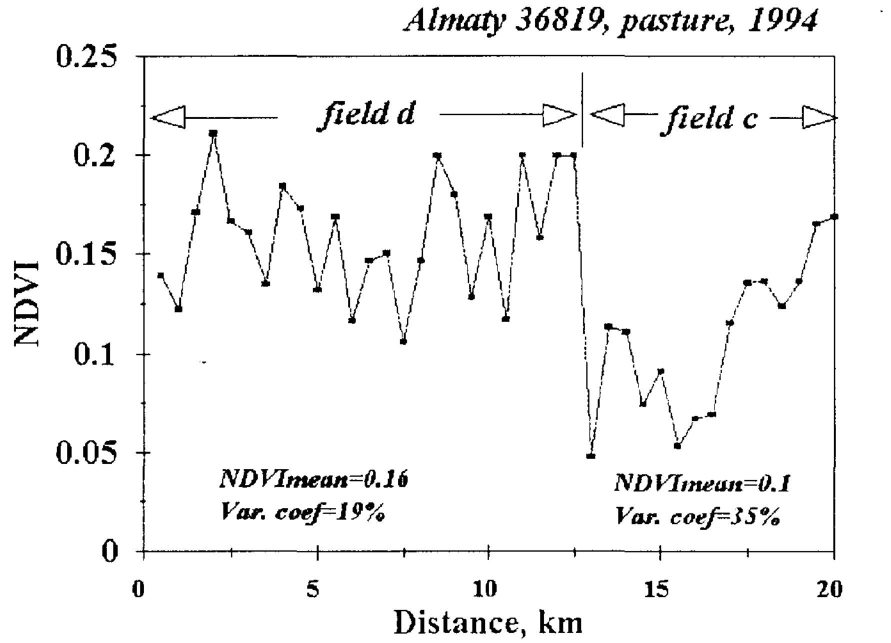
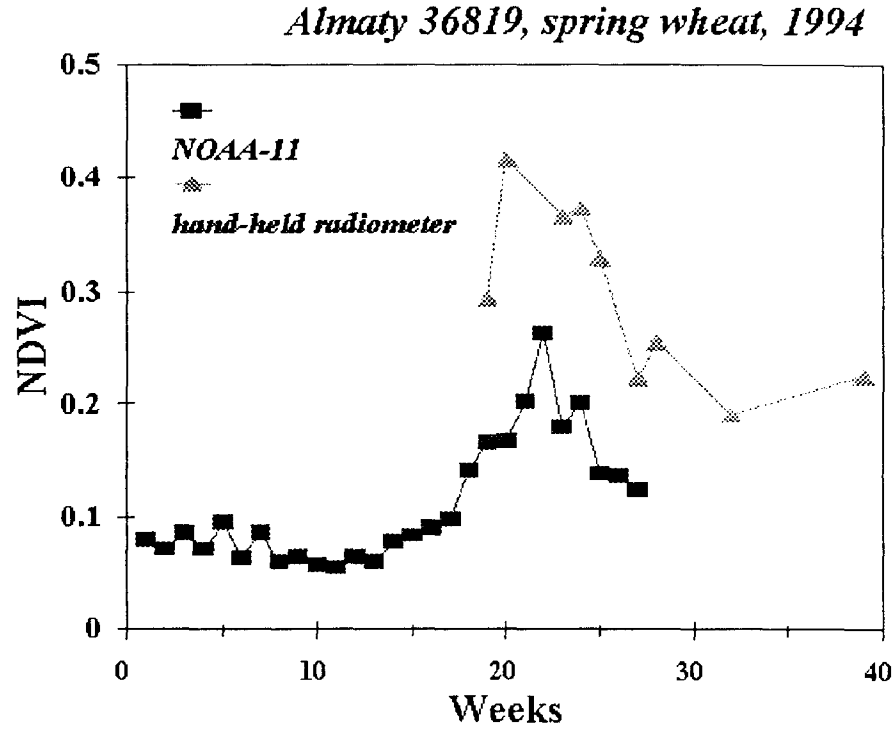


Fig. 9. Spatial variation of NDVI along a 20 km transect through pasture fields (c) and (d) at station 36819 (Almaty) measured by photometer DPF on board a helicopter on August 12, 1994.



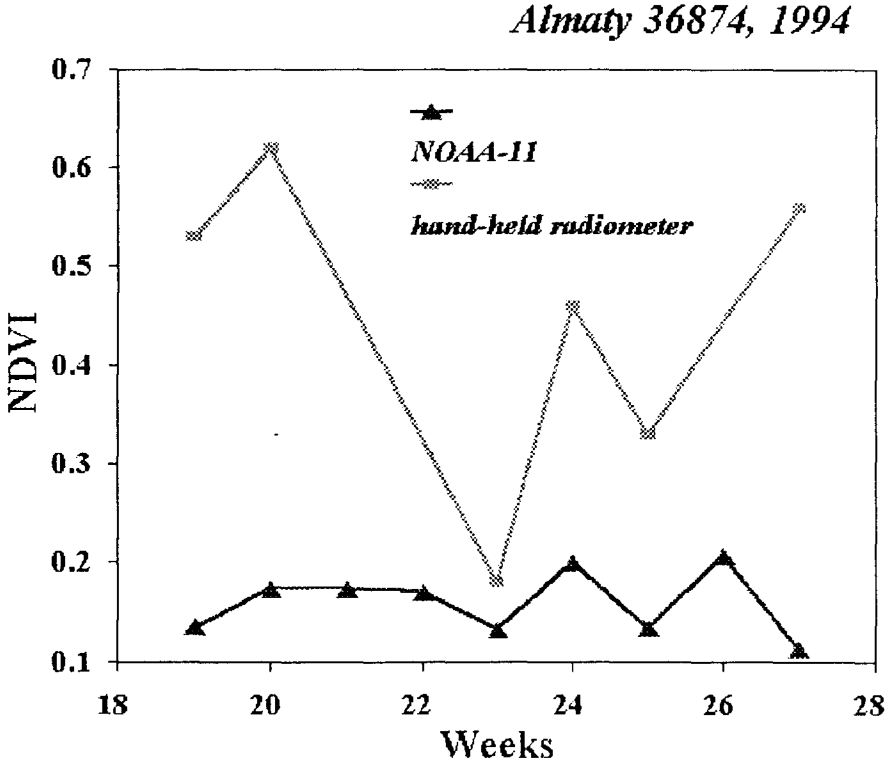


Fig. 10. Averaged NDVI for 3 by 3 of 16 km resolution pixels calculated from the NOAA-11 polar-orbiting satellite and median NDVI retrieved from hand-held radiometer measurements shown in Fig. 8.

unreliable after week 27 due to deterioration of satellite data. Figure 10 also shows that ground measurements of NDVI are higher than those by satellite due to known effects of light attenuation by the atmosphere.

5.4.2 Spatial variation of biomass

One of the important result of this project was the simultaneous measurement of biomass and radiances. This allowed us to compare biomass and NDVI dynamics. Figure 11a shows the dynamics of pasture biomass at four fields of station 36819. Biomass at plot (b) was much higher than at other plots. As a result, the average biomass for all plots was relatively large (Fig. 11b) as well as standard deviation, which accounts for 30 to 40 percent of average biomass variation.

The relation between ground-measured 4-plot median NDVI and biomass is very strong (Fig. 12a). However, if all observations of biomass and NDVI are included (all four plots and all nine dates), then the relationship deteriorates and levels off for the biomass between 4 and 6 t/ha. Similar behavior of the median NDVI/biomass relationship is observed for spring barley (station 36874, Fig. 13), although the number of observations especially for biomass above 5 t/ha, is not sufficient to reach a reliable conclusion.

5.5 Large area calibration of the Vegetation Condition Index

The results of section 5.4 above clearly indicated that the vegetation indices can 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 can be used as an indicator of vegetation productivity on a large area. Unfortunately, the volume of work in large-area data collection and processing did not allow us to fulfill this task for the entire area of K. We were only able to collect, process and explore a limited amount of data.

5.5.1. Specifics of data preparation

The average VCI data for the area of 48 km by 48 km (3 by 3 GVI pixels) were collected around six weather stations with the experimental plots. These stations are located in southern (Almaty region), central (Jeskazgan), and northern

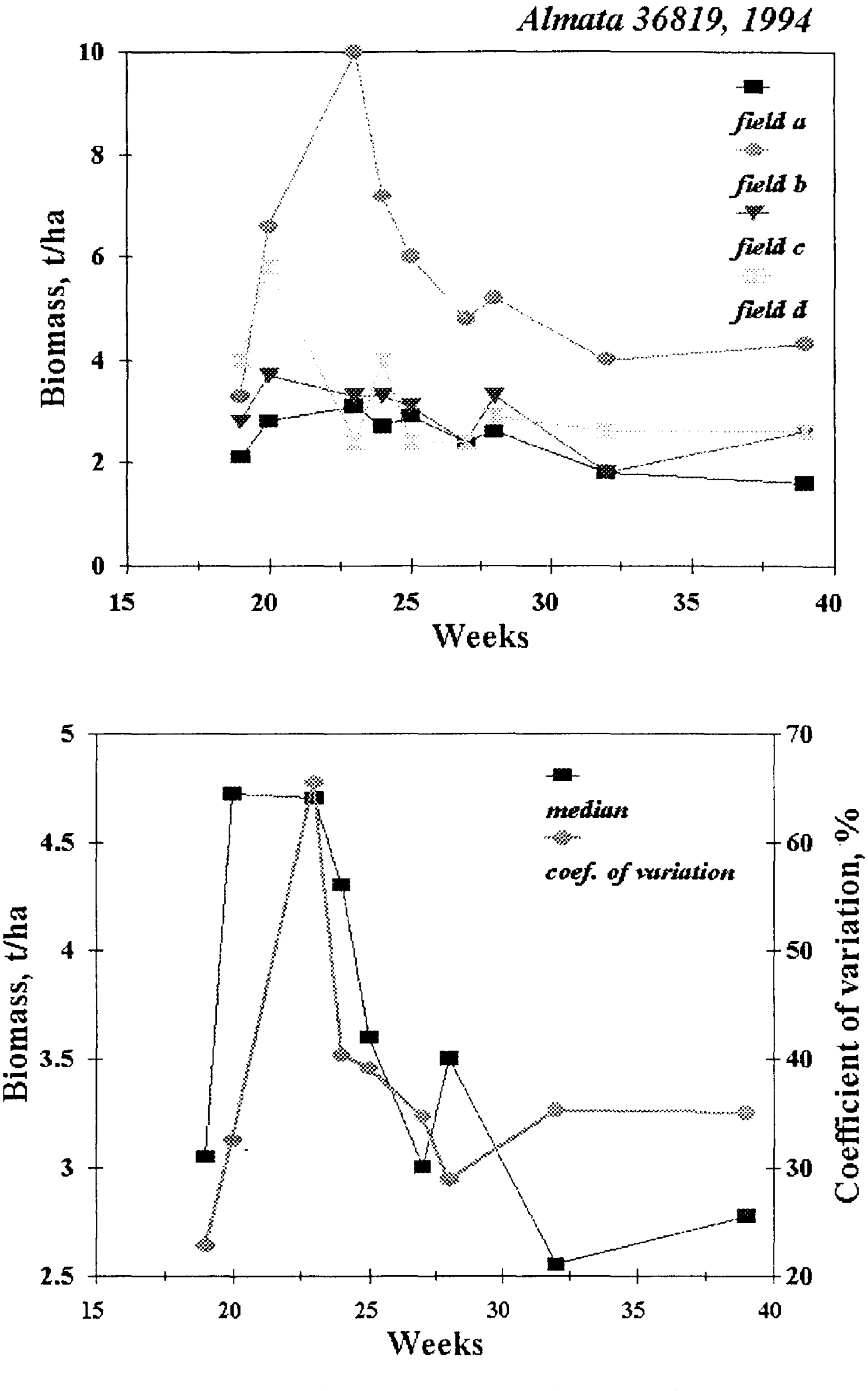


Fig. 11. Seasonal dynamics of biomass measured at experimental plots (100 by 100 m) of four fields (a,b,c,d) for station 36819, pasture, (A), and three fields (a,b,c) for station 36874, spring barley (B) in the Almaty region in 1994. For each plot, biomass biomass was derived as an average from four measurements.

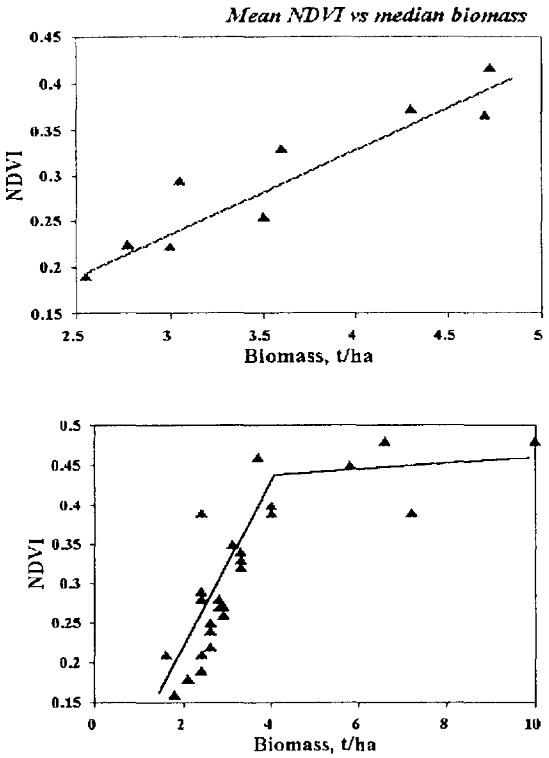


Fig. 12. NDVI versus biomass for four pasture plots of station 36819 in 1994. (A) NDVI was derived from hand-held radiometer measurements, and biomass was averaged from four measurements at each plot; (B) median NDVI and median biomass calculated for four plots of fields (a,b,c,d).

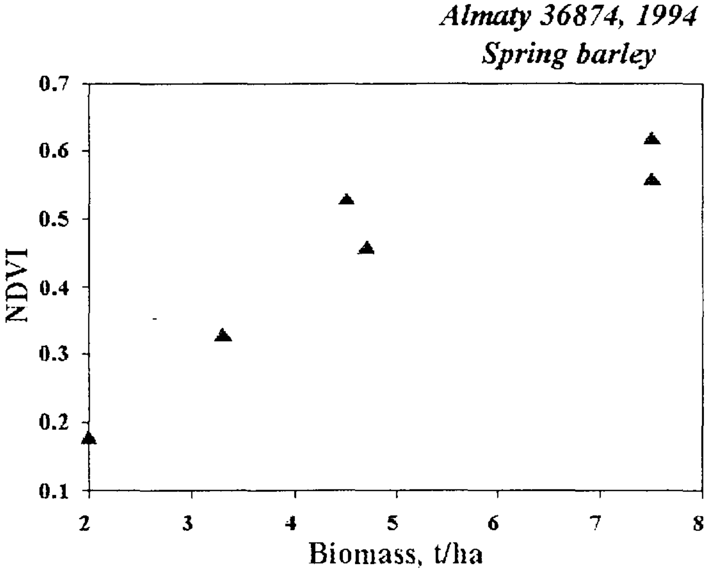


Fig. 13. Median NDVI versus median biomass for three spring barley plots of station 36874 in 1994. (A) NDVI was derived from hand-held radiometer measurements, and biomass was averaged from four measurements at each plot.

(Akmola) Kazakhstan. Analysis was done for two years with different weather conditions, 1991 dry and 1992 wet. As a result of these conditions, agricultural crops production was lower in 1991 (total grain 11,992 million metric tons, Table 2) and higher in 1992 (29,772).

In addition to satellite data, data on density of vegetation (number of plants per m^2) were collected for the growing season several times (5 to 11) from 1985 to 1993. Since the VCI characterizes both spatial distribution of vegetation and fluctuation of vegetation between the years, the ground measurements of density were also expressed in terms of multi-year variation. Therefore, minimum, maximum, and median values of the density were calculated from the 1985-1993 data base. Each measurement, D_i, was expressed as a deviation either from minimal, D_{min}, or median, D_{med}, values and normalized to the range of multi-year fluctuation of the density, $(D_{max} - D_{min})$:

$$\delta D,(\%) = (D_i - D_x)/(D_{max} - D_{min})$$

The VCI was compared with the density characteristic δD.

5.5.2. Ground and satellite data comparison

Since vegetation density measurements were carried out at a single point in a field, there is a chance that these measurements might not have been representative for the entire field. Therefore, we tested two possibilities: which of two criteria, the multi-year minimum (similar to the VCI, which is an aerial index) or multi-year median, is more suitable for estimating density deviation. Figure 14 shows seasonal dynamics of density deviation from (A) the minimum criterion and (B) the median criterion at station 36819 (Almaty). As can be seen, both estimates show that the selected two years were extremely different. The 1991 dry year had very low density of vegetation throughout the entire season, while the 1992 wet year had low density of vegetation only at the very beginning (up to week 23) and density had increased considerably by the end of the growing season (weeks 33 to 40). In relation to the selected criteria (minimum and median) we should emphasize that the variation of density for the driest period (weeks 18 to 26) was larger for the median (-20 to -50) rather than for the minimum (near zero).

These findings are supported by the correspondence between deviation density (DD) and VCI dynamics in 1991 (Fig. 15 a). The VCI and median-derived DD had a similar decreasing tendency during weeks 18-22 and an increasing tendency during weeks 23-26, while the minimum-derived DD did not show this similarity. This is natural, since the sensitivity at extreme values is higher for median rather than minimum criteria. It is important to indicate that there is a good match between VCI derived conditions and DD throughout the whole season, for the two extremely different years, especially for the median-derived

Table 2. Area, yield and production of selected grain crops, sunflower, and sugar beets in Kazakhstan (after USDA, 1994).

Kazakhstan: Area , yield, and production of selected grain crops (cleanweight), sunflowerseed and sugarbeets

Year	Wheat			Barley			Rye	Oats	Millet	Corn	Buck-wheat	Rice	Pulses	Total grain	sunflower-seed	sugar-beets
	Winter	Spring	Total	Winter	Spring	Total										
Area								**1,000 hectares**								
1981-85 avg.	1,089	15,246	16,335	na	na	6,737	354	446	802	123	198	137	169	25,352	101	68
1986-90 avg.	1,086	13,764	14,849	38	6,774	6,819	598	415	725	128	193	131	172	24,109	118	50
1988-92 avg.	1,127	13,006	14,134	47	6,519	6,566	651	422	821	129	275	126	161	23,361	176	49
1986/87	1,062	14,538	15,600	46	6,643	6,727	432	450	692	119	177	129	164	24,563	96	62
1987/88	1,155	14,156	15,311	30	6,841	6,871	489	483	677	119	179	133	184	24,525	104	56
1988/89	915	13,961	14,876	30	7,033	7,063	577	350	699	137	177	135	183	24,290	122	42
1989/90	1,097	13,293	14,390	29	6,744	6,773	723	408	774	134	215	133	172	23,812	131	45
1990/91	1,199	12,871	14,070	53	6,607	6,660	769	382	781	129	218	124	159	23,356	137	44
1991/92	1,206	12,250	13,456	60	6,554	6,614	562	512	847	121	318	118	152	22,753	190	45
1992/93	1,220	12,657	13,877	61	5,657	5,718	623	456	1,003	126	447	121	140	22,596	298	68
1993/94	1,313	11,437	12,750	63	6,938	7,001	na	549	527	117	409	112	119	22,250	271	65
Yield								**tons per hectare**								
1981-85 avg.	0.92	0.75	0.75	0.99	0.79	0.79	0.60	0.97	0.47	4.14	0.40	4.38	0.62	0.79	0.94	25.6
1986-90 avg.	1.53	0.92	0.97	1.78	0.99	0.99	0.92	1.10	0.80	3.88	0.51	4.51	0.80	1.00	0.99	28.9
1988-92 avg.	1.38	0.87	0.91	1.86	0.96	0.97	0.95	1.05	0.67	3.35	0.53	4.34	0.72	0.94	0.79	20.2
1986/87	1.25	1.06	1.07	1.08	1.06	1.06	0.85	1.37	0.56	4.25	0.42	4.55	0.91	1.08	0.87	27.9
1987/88	1.95	0.98	1.05	1.96	1.00	1.00	0.69	0.95	0.82	4.03	0.40	4.54	0.79	1.05	1.12	32.0
1988/89	1.48	0.77	0.82	2.00	0.83	0.83	0.95	0.98	0.82	4.09	0.66	4.65	0.72	0.86	1.14	31.8
1989/90	1.32	0.70	0.75	1.72	0.78	0.78	1.03	0.61	0.59	3.58	0.25	4.16	0.62	0.79	0.80	26.7
1990/91	1.64	1.11	1.15	2.12	1.27	1.28	1.09	1.60	1.20	3.44	0.80	4.65	0.97	1.22	1.03	26.0
1991/92	1.02	0.46	0.51	1.52	0.46	0.47	0.85	0.45	0.28	2.72	0.43	4.40	0.43	0.53	0.57	16.1
1992/93	1.43	1.31	1.32	1.95	1.48	1.49	0.85	1.59	0.45	2.91	0.51	3.86	0.88	1.32	0.41	17.2
1993/94	1.47	0.84	0.91	1.78	1.01	1.02	na	1.46	0.44	3.03	0.32	3.61	0.79	0.97	0.40	13.8
Production								**1,000 tons**								
1981-85 avg.	1,018	11,380	12,398	103	5,261	5,364	217	420	374	503	80	597	105	20,082	94	1,785
1986-90 avg.	1,671	12,728	14,399	92	6,645	6,737	568	456	583	493	98	590	138	24,108	117	1,434
1988-92 avg.	1,562	11,301	12,863	93	6,159	6,251	627	433	532	436	142	550	116	22,004	123	1,108
1986/87	1,328	15,415	16,743	91	7,004	7,095	369	616	391	505	74	586	150	26,562	83	1,724
1987/88	2,255	13,853	16,108	122	6,807	6,929	338	459	549	477	72	606	145	25,721	117	1,804
1988/89	1,354	10,808	12,162	84	5,766	5,850	548	345	577	561	117	626	132	20,970	139	1,321
1989/90	1,451	9,332	10,783	50	5,260	5,310	745	251	459	479	53	555	107	18,797	105	1,188
1990/91	1,966	14,231	16,197	112	8,389	8,500	839	610	940	442	174	579	154	28,488	141	1,134
1991/92	1,298	5,591	6,889	100	2,985	3,085	480	231	235	330	136	521	66	11,992	108	726
1992/93	1,743	16,542	18,285	118	8,393	8,511	525	727	447	368	230	467	123	29,772	122	1,170
1993/94	1,934	9,651	11,585	112	7,037	7,149	na	802	232	355	130	403	94	21,631	107	900

na = not available.

Sources: USDA; Goskomstat Kazakhstana.

JOINT AGRICULTURAL WEATHER FACILITY (NOAA/USDA)

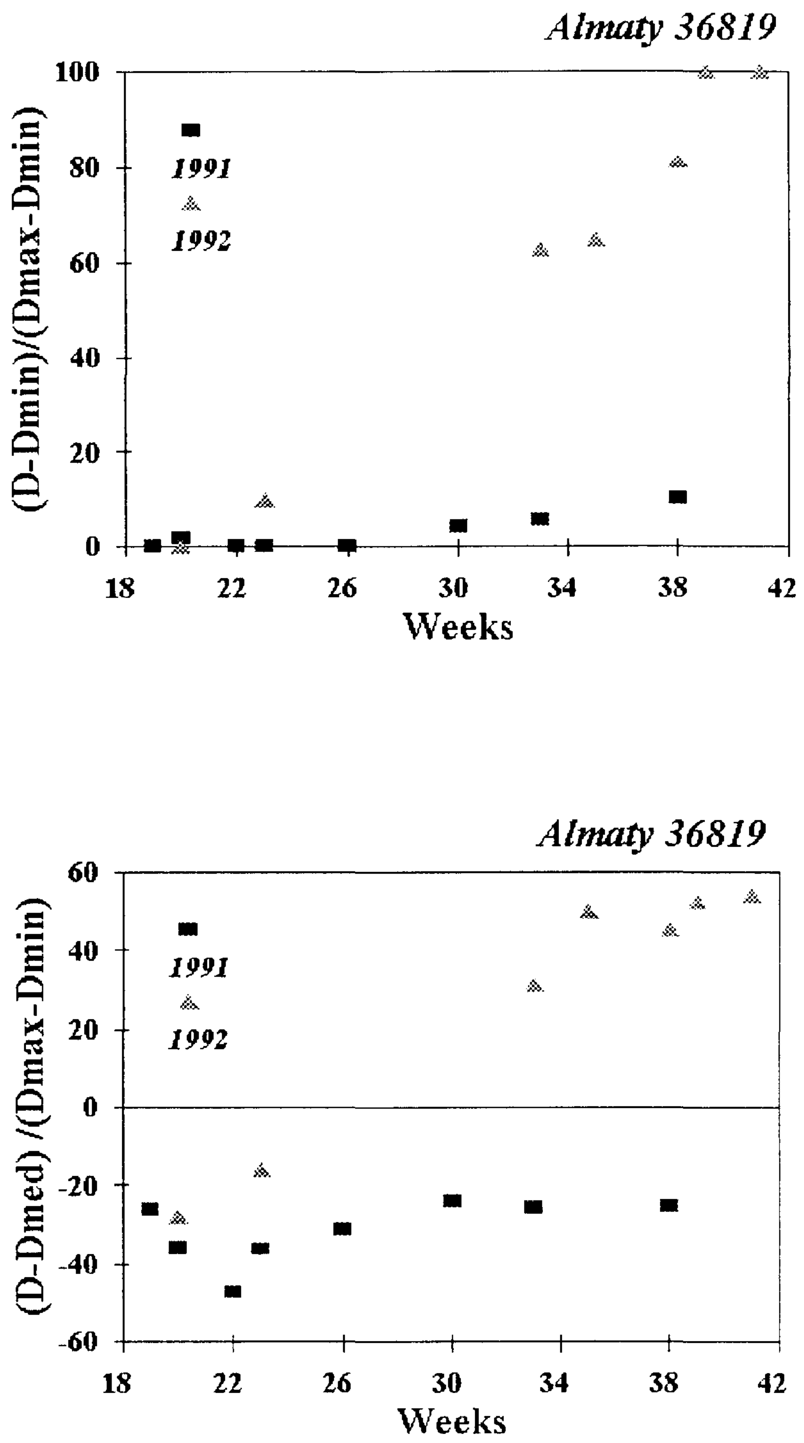


Fig. 14. Seasonal dynamics of density deviation (DD) from multi-year minimum (A) and median (B) values, normalized to the 1985-1993 density fluctuation (D_{max}-D_{min}). Almaty region, station 36819.

DD (Fig. 15 and 16). In the further discussion we will concentrate on the median-derived DD.

The Figures 17 through 21 show VCI and median-derived DD dynamics in 1991-1992 for the rest of the experimental sites. Analysis of these figures clearly indicate that for very different ecological zones, extremely different years, throughout the entire season and for different types of vegetation there is a very good match between satellite- and ground-derived estimates of vegetation conditions. The ecological zones of the discussed data changed from dry in Jeskazgan (Fig. 20 and 21) to wetter in Almaty (Fig. 15b, 16b, 17) regions. Conditions for vegetation growth were very dry in 1991 and wet in 1992. The most interesting fact is that the very beginning of the 1991 season was quite favorable (Fig. 18a, 19a, 20a, 21a). In 1992 the situation was opposite, conditions at the beginning of the growing season were unfavorable and in the second part were favorable (Fig. 18b, 19b, 20b, 21b). All stations had pasture-type of vegetation except for Akmola, 28978 which had spring wheat (Fig. 18).

The good match between VCI- and density-derived conditions shown in Figs. 17-21 allows us to correlate these characteristics. The correlation for individual stations is shown in Figs. 22 to 24. The correlation is strong (r^2=0.72-0.92) with an estimating error of density between 10 to 15 percent. Only one station 35744 (Almaty), Fig. 22, had a lower correlation (r^2=0.47) because weather conditions were more favorable and the variation of the VCI was smaller.

We should again point out that the higher values of correlation are partially explained by the fact that we are discussing two years with very different weather conditions. However, it is important to emphasize that for some of these stations 36819 (Fig. 22a), 28987 (Fig. 23a), 35376 (Fig. 23b), and 35478 (Fig. 24a) there is an overlap of the points for the two different years. We should also indicate that there is some saturation of the VCI for extreme values of median-derived DD (Figs. 23b, 24a,b). This saturation of VCI for high vegetation density can be explain by the saturation of NDVI for chlorophyll content above 3-5 $\mu g/cm^2$ (Buschmann and Nagel, 1993, Gitelson and Merzlyak, 1994a,b) and for Leaf Area Index above 4-5 (Baret and Guyot, 1991; Danson and Plummer, 1995).

Despite of the fact that the selected stations were located in very different climatic and ecological zones, with elevation changing from 300 to 700 m and a large range of NDVI variation (over space and season) from 0.05 to 0.47, all station points were located around the same correlation line (Fig. 25). Although there are some local differences, correlation was high r^2 = 0.76 with an estimating error of less than 16 percent. 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. This corresponds to our conclusions in Kogan, 1995a. One of the main causes for scattering of the VCI/DD relationship is the difference

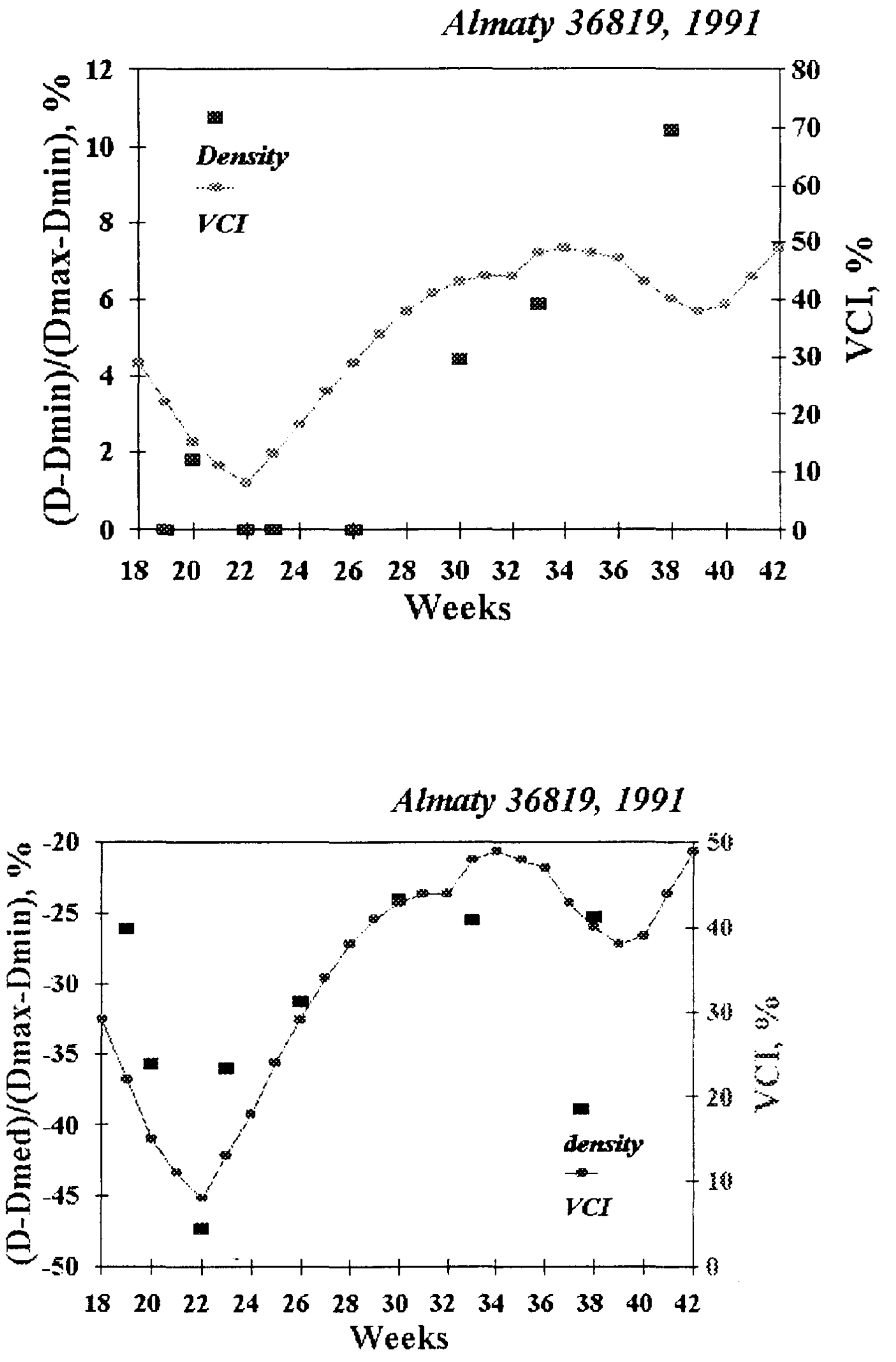


Fig. 15. Comparison of the VCI and multi-year density deviation (A) from minimal, and (B) median. Almaty region, station 36819, 1991.

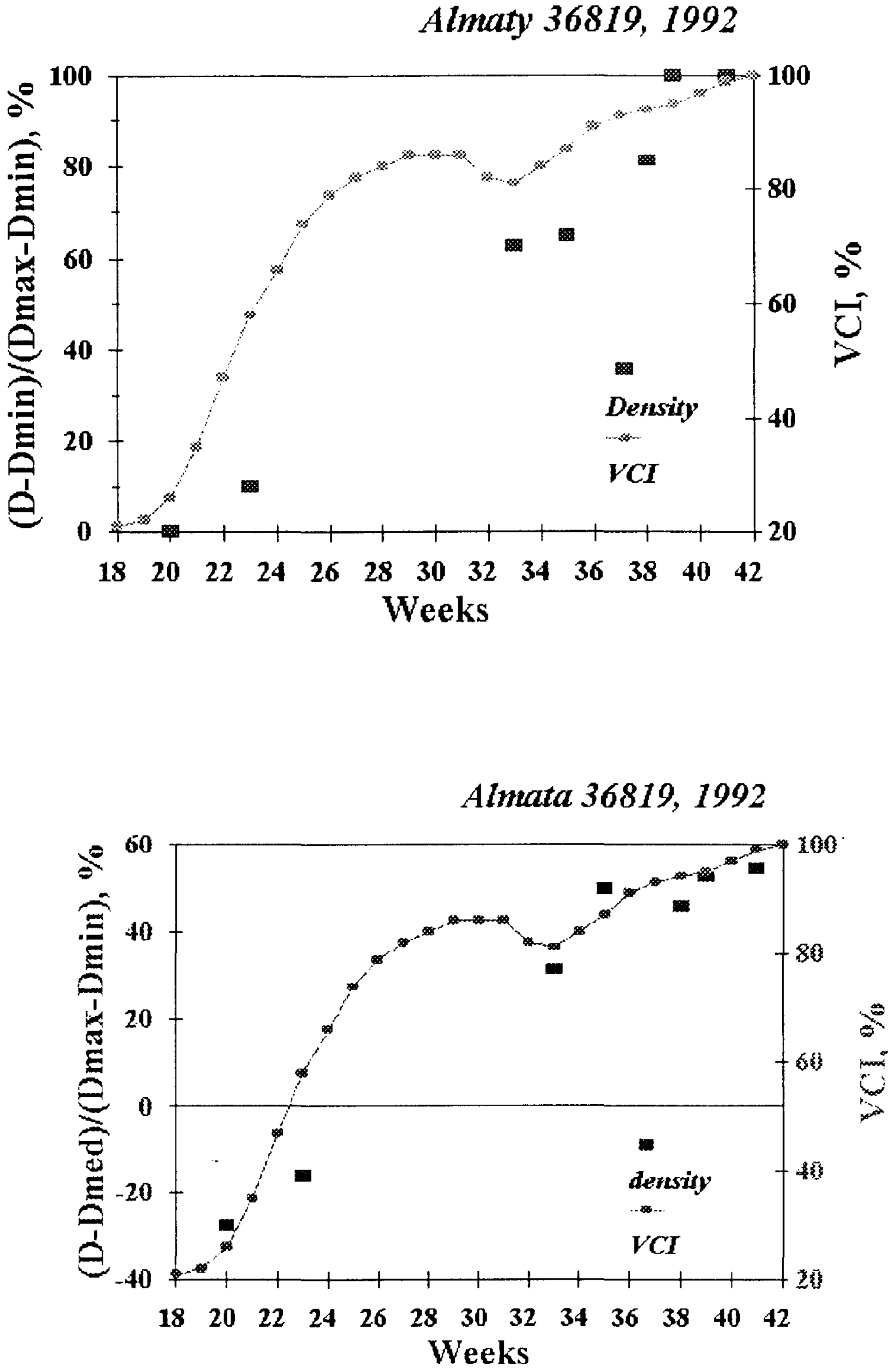
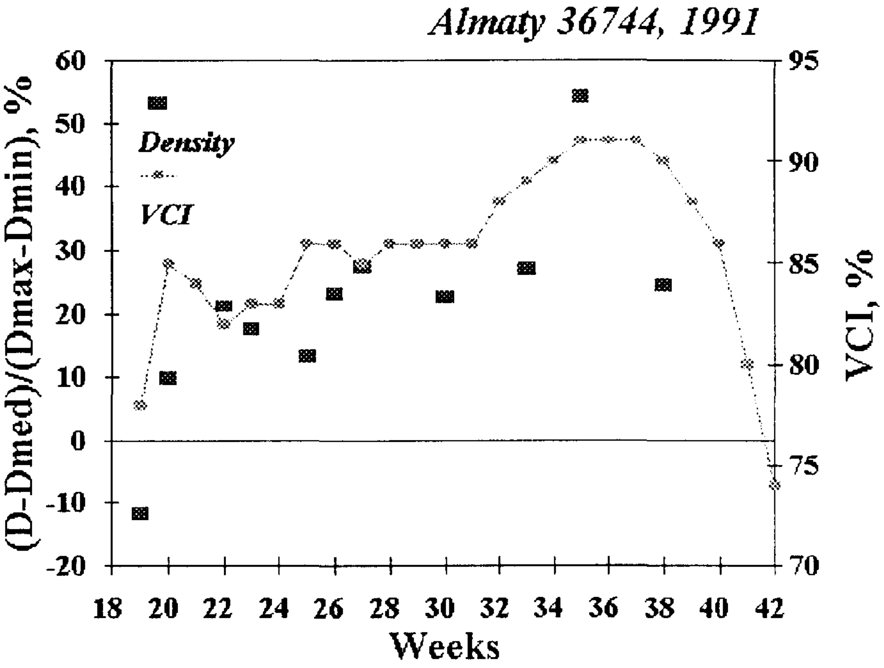


Fig. 16. Comparison of the VCI and multi-year density deviation (A) from minimal, and (B) median. Almaty region, station 36819, 1992.



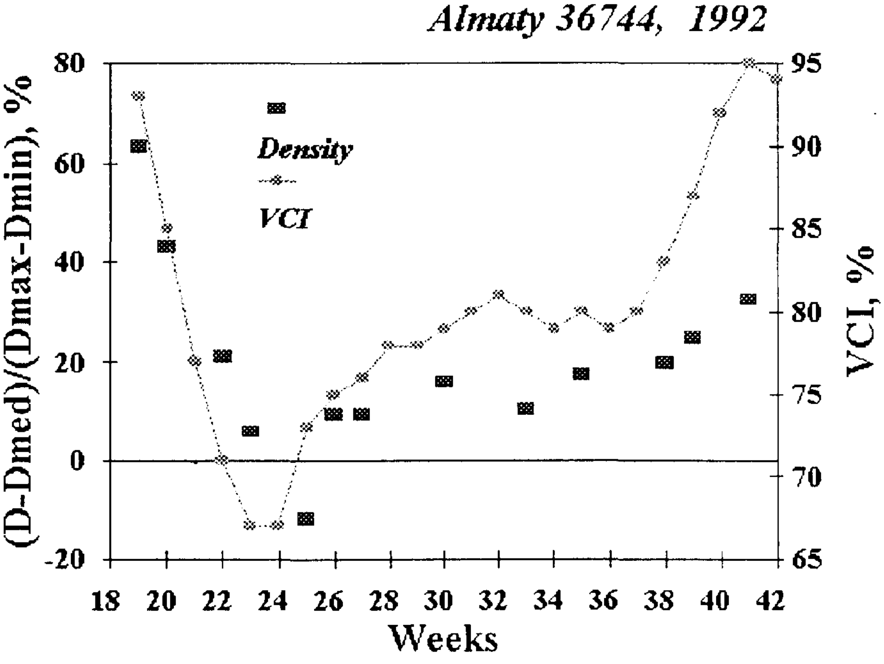
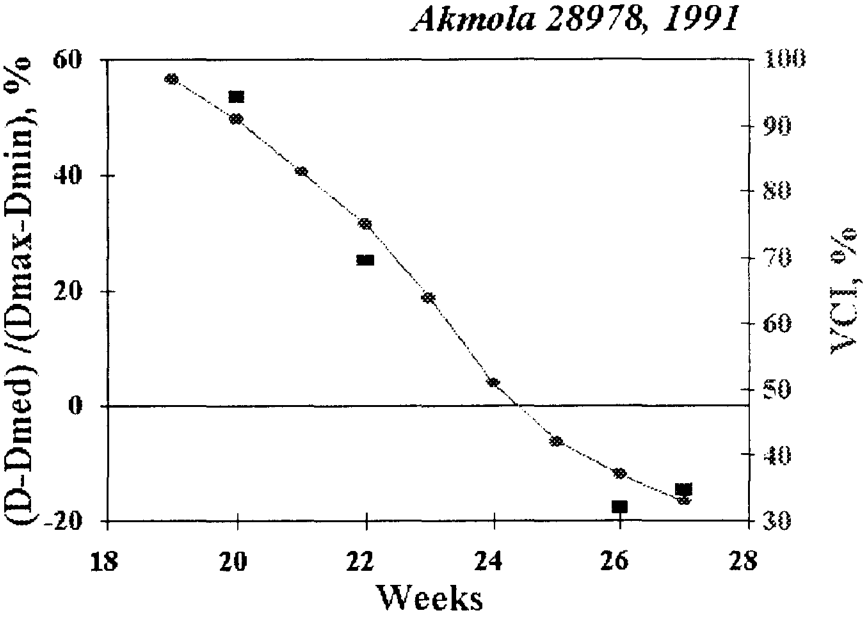


Fig. 17. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Almaty region, station 36744.



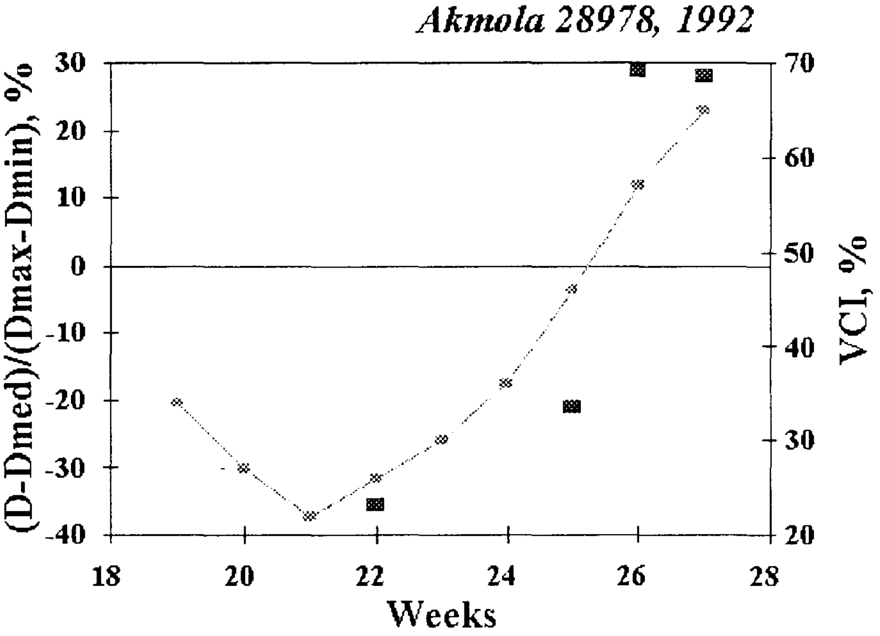
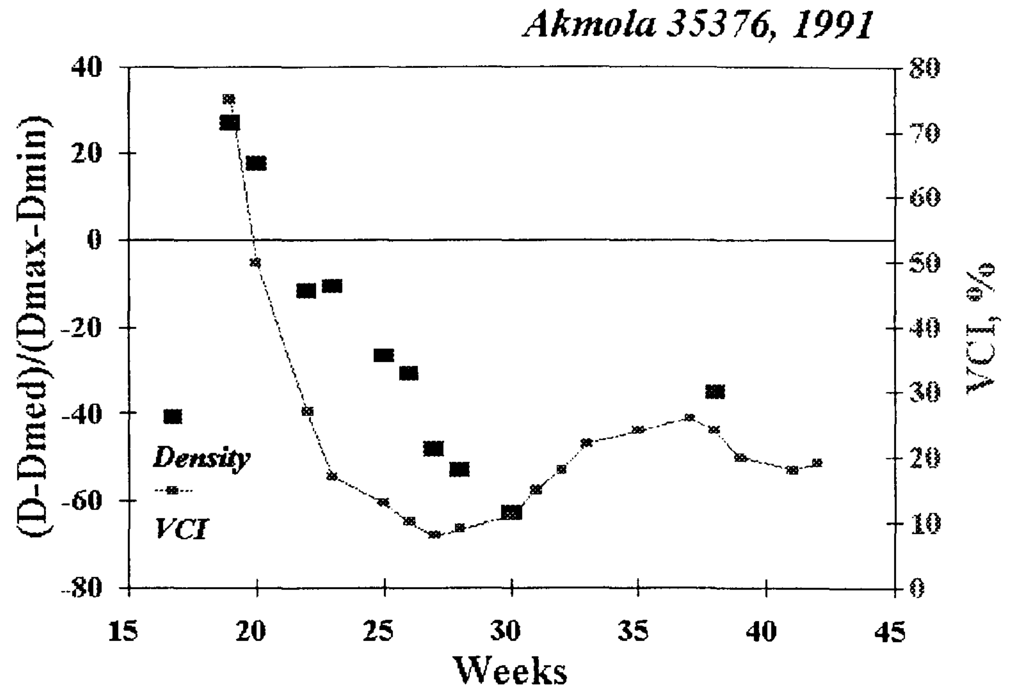


Fig. 18. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Akmola region, station 28978.



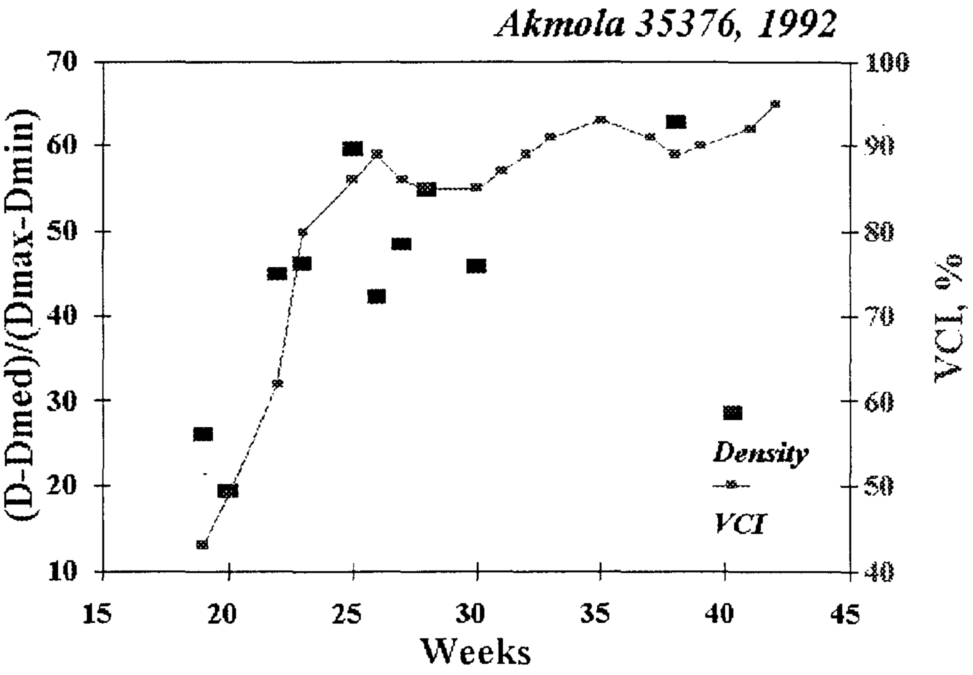


Fig. 19. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Akmola region, station 35376.

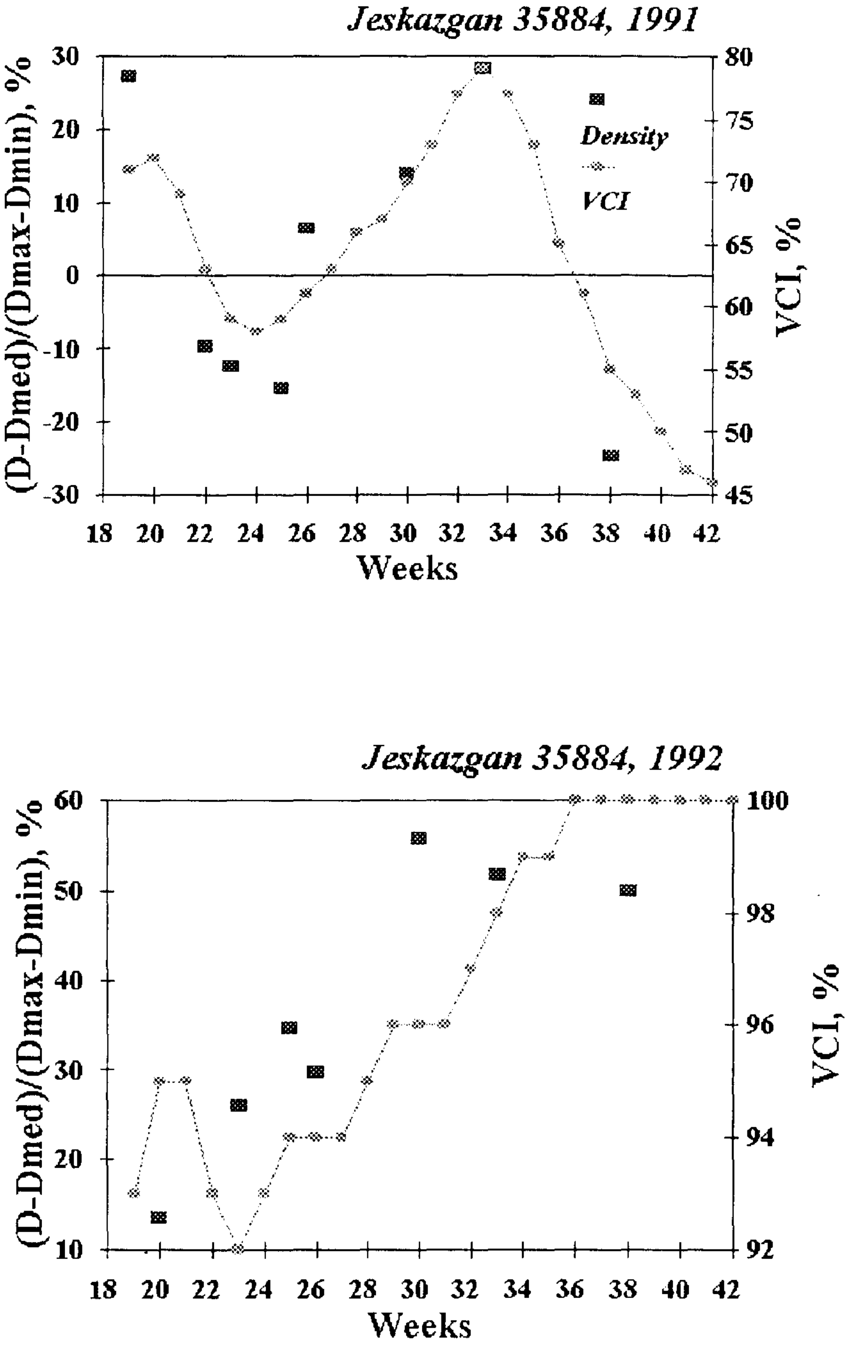
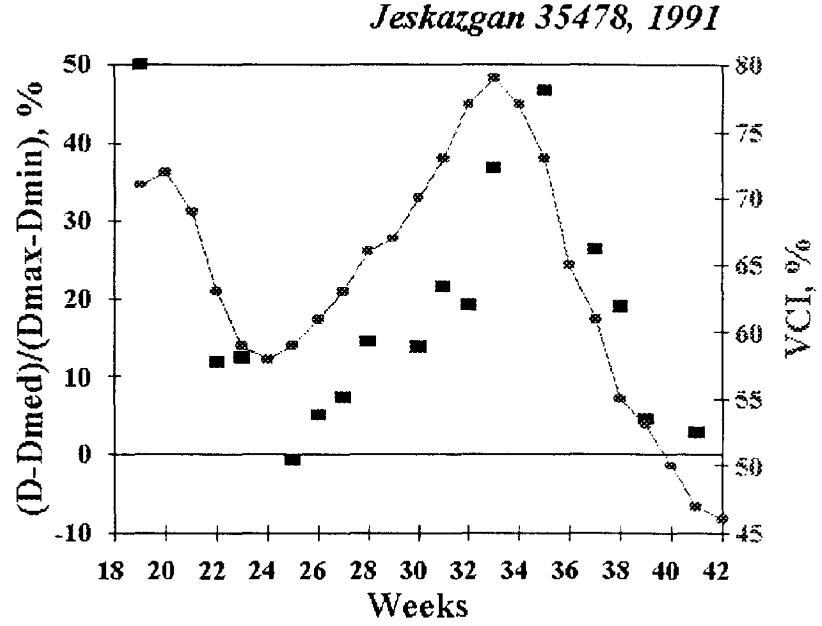


Fig. 20. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Jeskazgan region, station 35884.



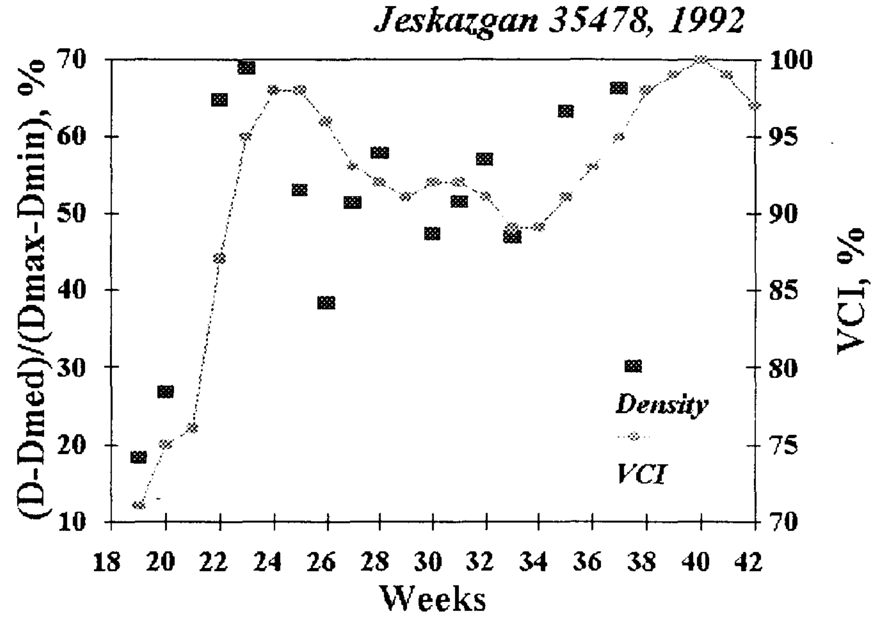


Fig. 21. Comparison of the VCI and multi-year density deviation from median (A) 1991, and (B) 1992. Jeskazgan region, station 35478.

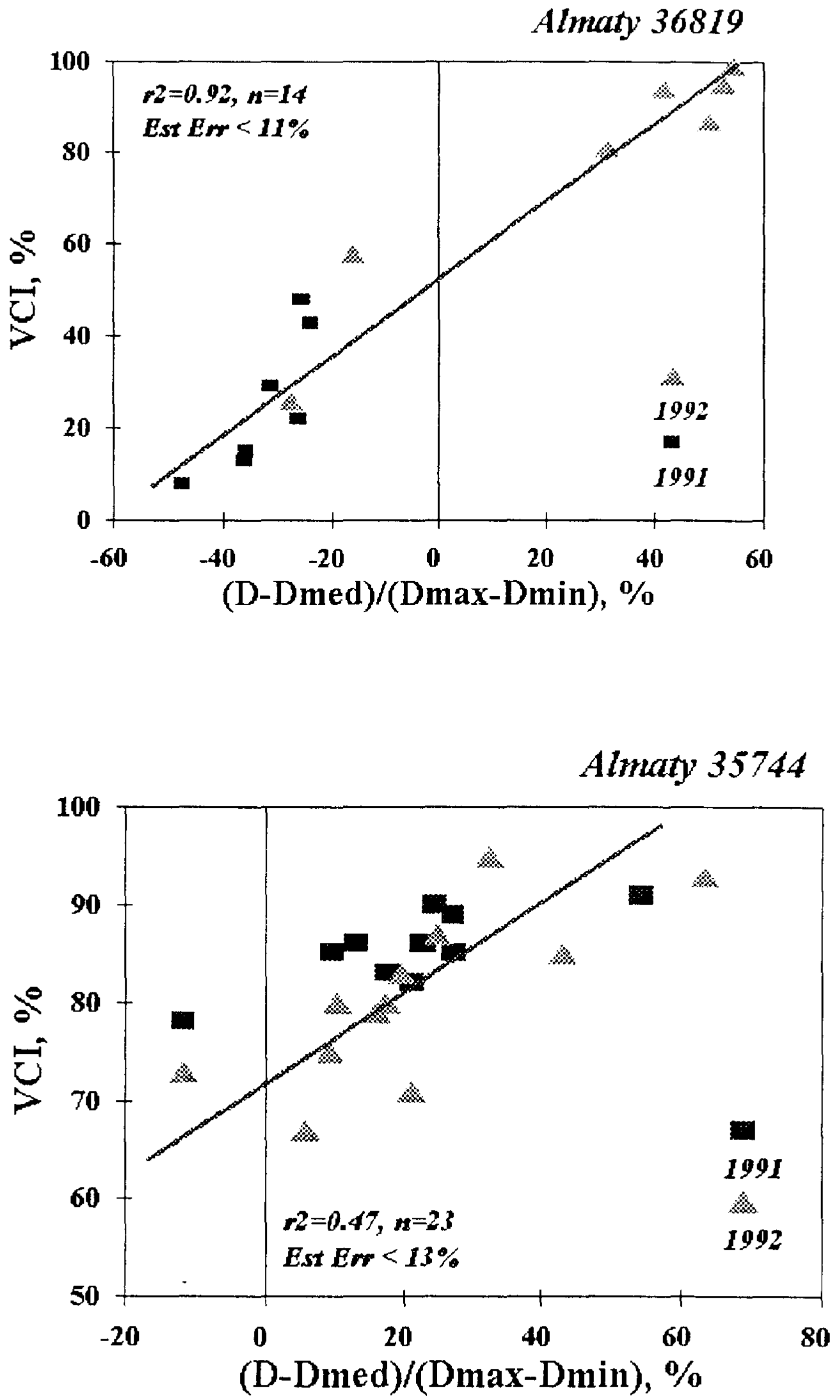


Fig. 22. Correlation between the VCI and median-derived density deviation for Almaty 36819 (A) and 35744 (B).

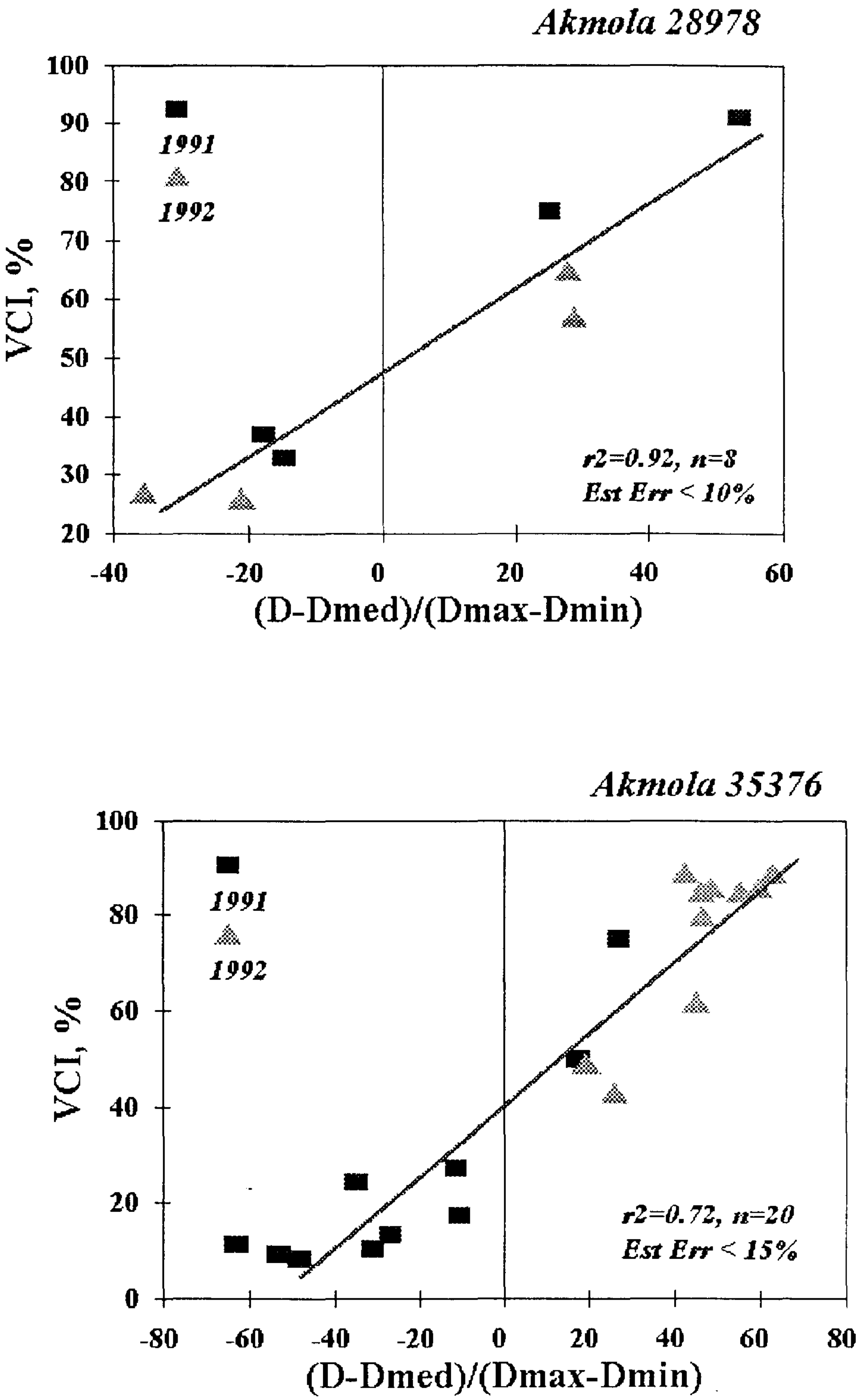


Fig. 23. Correlation between the VCI and median-derived density deviation for Akmola 35376 (A) and 28978 (B).

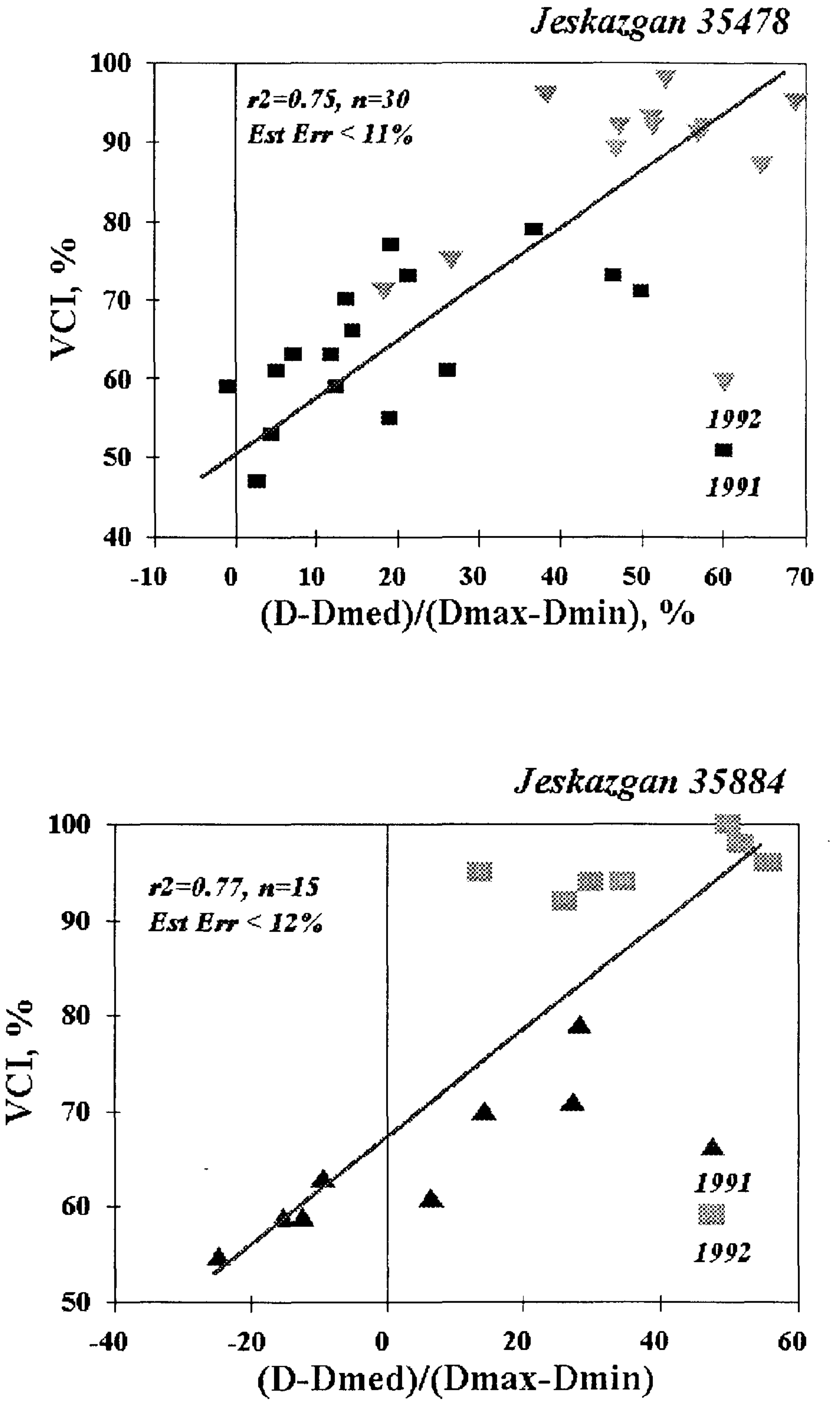


Fig. 24. Correlation between the VCI and median-derived density deviation for Jeskazgan 35478 (A) and 35884 (B).

between aerial estimates from satellite data and point measurements of ground density which was discussed in chapter 5.4.1 and 5.4.2.

These findings are the first step in validating the VCI in Kazakhstan. First time it was shown that the VCI-derived vegetation condition data can be effectively used for quantitative assessments of both vegetation state and productivity (density and biomass) over large areas. The second step should include quantitative calibration of the VCI against large area biomass, yield and production measurements of various crops and pastures with different vegetation types.

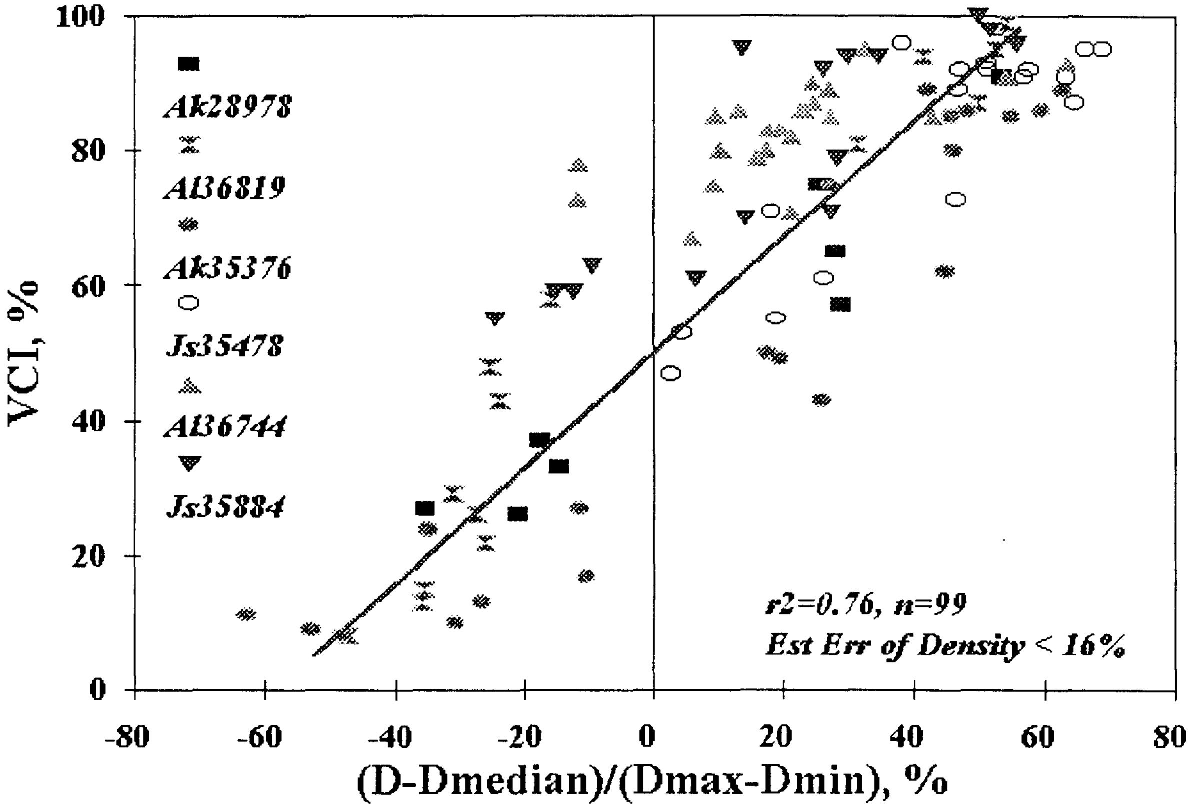


Fig. 25. Correlation between the VCI and median-derived density deviation for all six stations and two years (1991 and 1992).

5.6. VCI data for 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, and 1993. The last two droughts can be classified as a very severe.

5.6.1. Drought as weather hazard

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 et al. 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 et al. 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 impacts 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).

5.6.2. Large-area 1991 drought in Kazakhstan

In this section, we discuss application of VCI for monitoring of the 1991 drought for the entire area of Kazakhstan. This drought was the most intensive and wide-spread of the recent years. The VCI-derived 1991 drought data were compared with VCI assessments of the 1992 favorable year.

The image in Fig. 26 shows the VCI for the two indicated years at the end of June (week 26). As seen in 1991, the vegetation in the majority of Kazakhstan regions was under severe stress, while in 1992, stress vegetation was observed

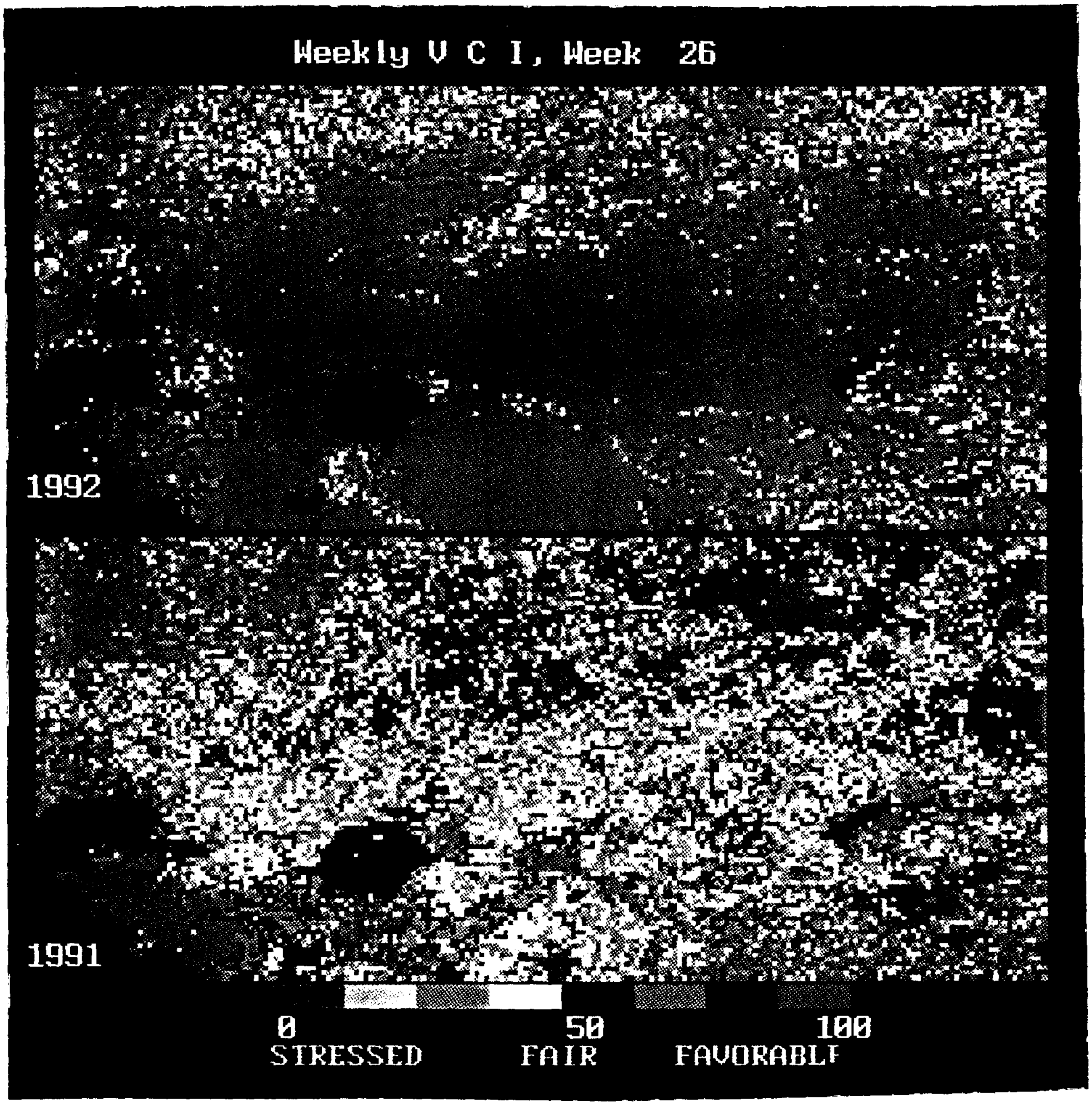


Fig. 26. Vegetation Condition Index for the end of June (week 26) 1991 and 1992 for each 16x16 km pixel.

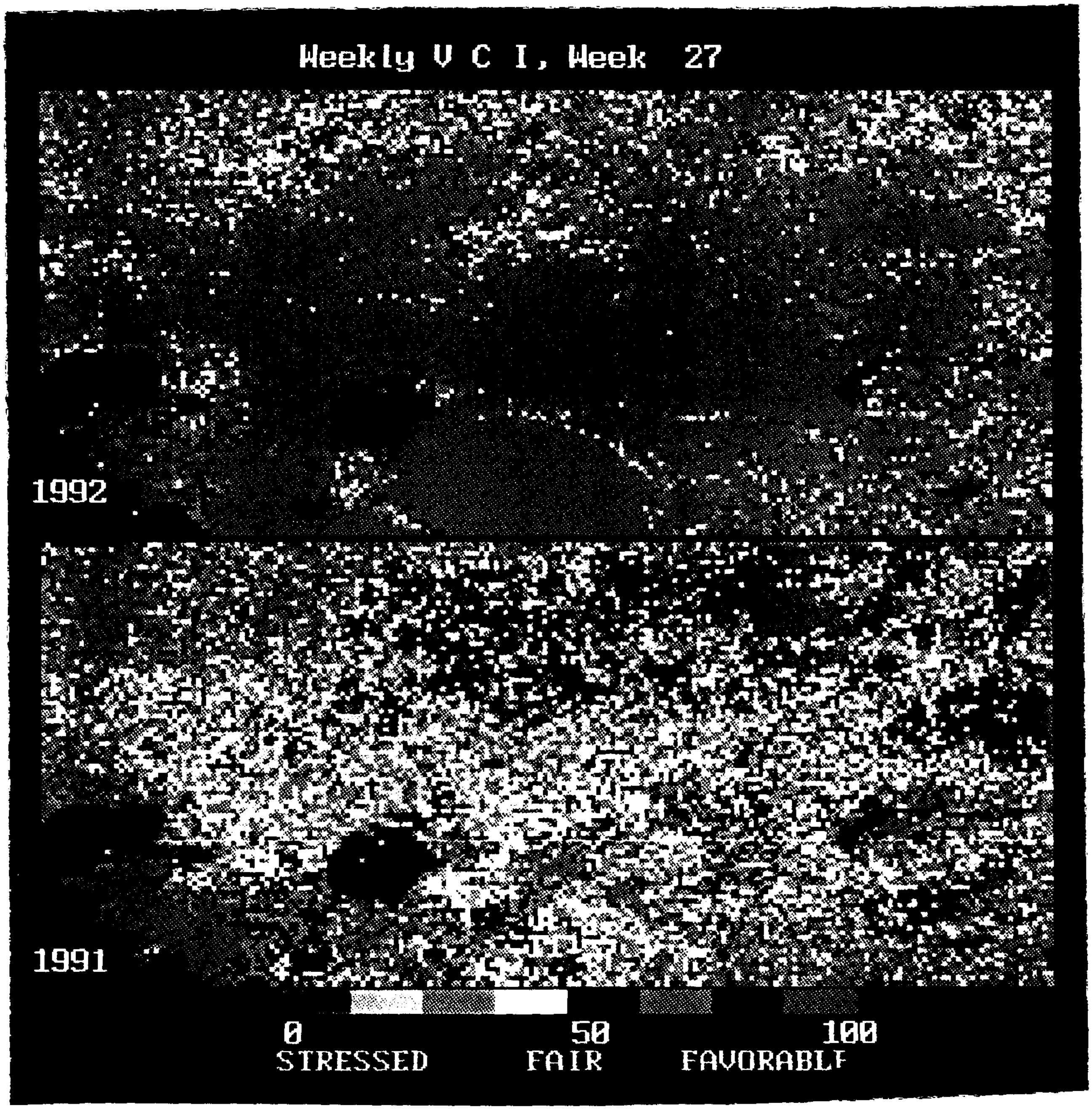


Fig. 27. Vegetation Condition Index for the beginning of July (week 27) 1991 and 1992 for each 16x16 km pixel.

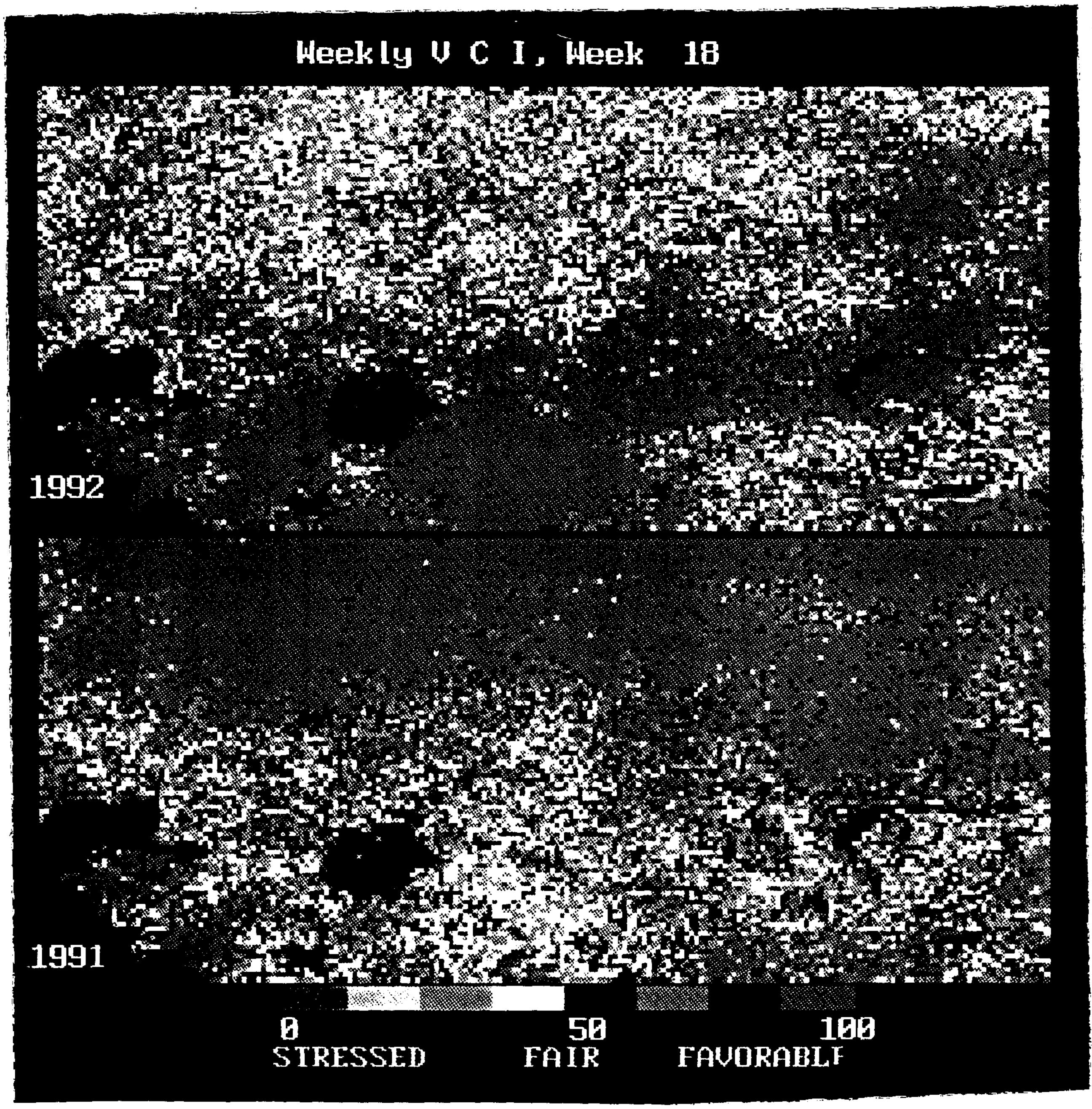


Fig. 28. Vegetation Condition Index for the beginning of May (week 18) 1991 and 1992 for each 16x16 km pixel.

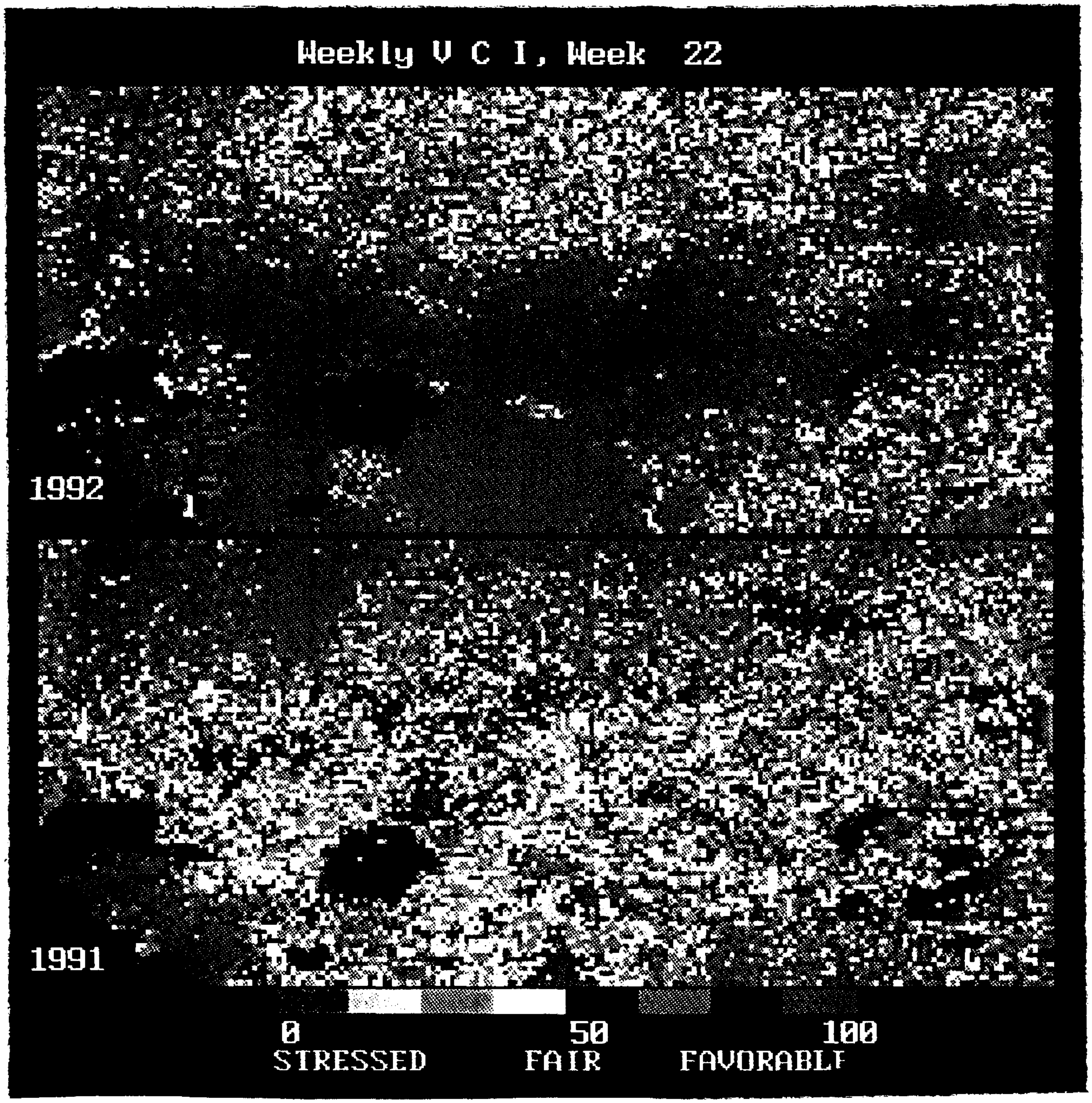


Fig. 29. Vegetation Condition Index for the end of May throught the beginning of June (week 22) 1991 and 1992 for each 16x16 km pixel.

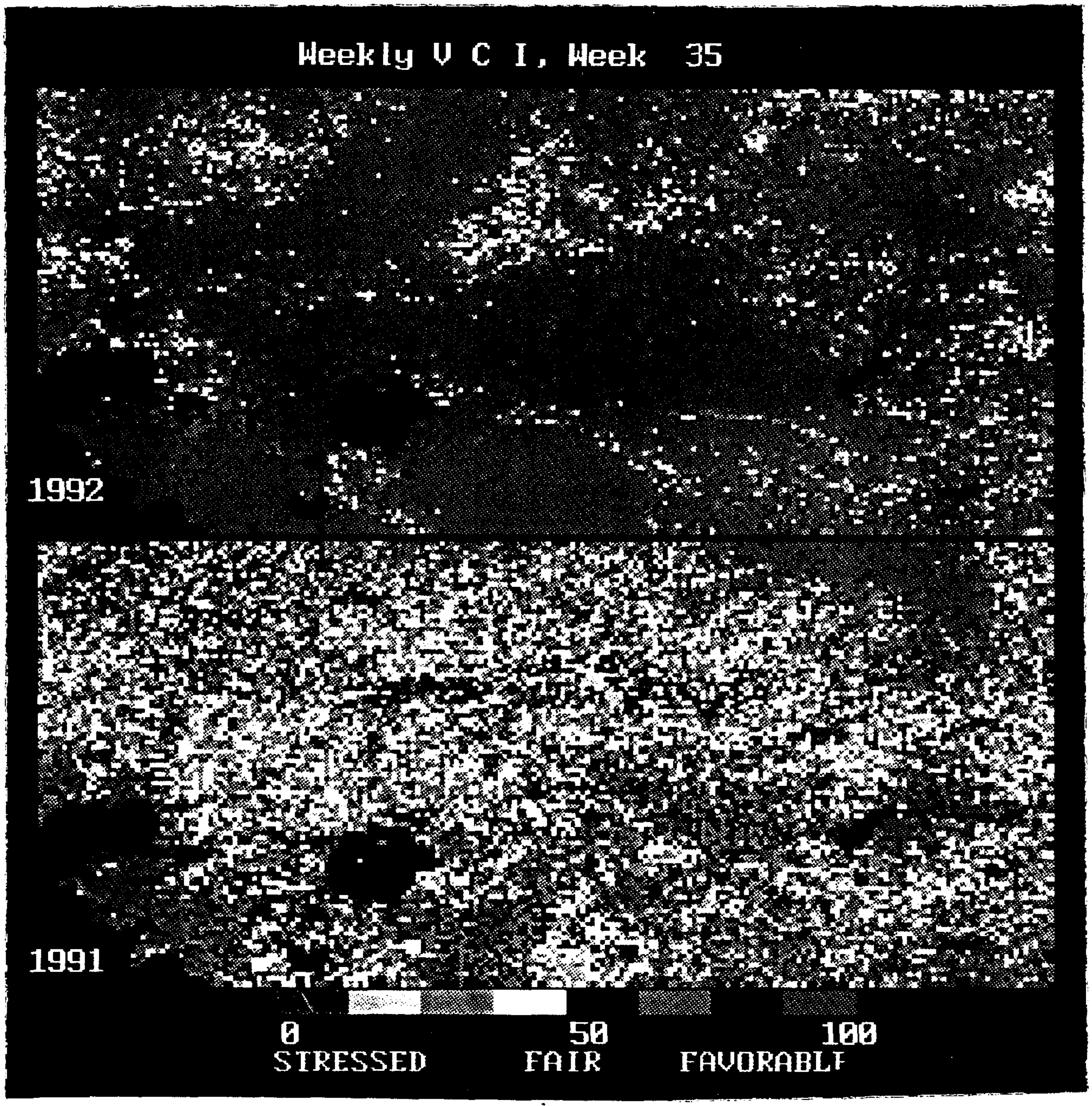


Fig. 30. Vegetation Condition Index for the end of August (week 35) 1991 and 1992 for each 16x16 km pixel.

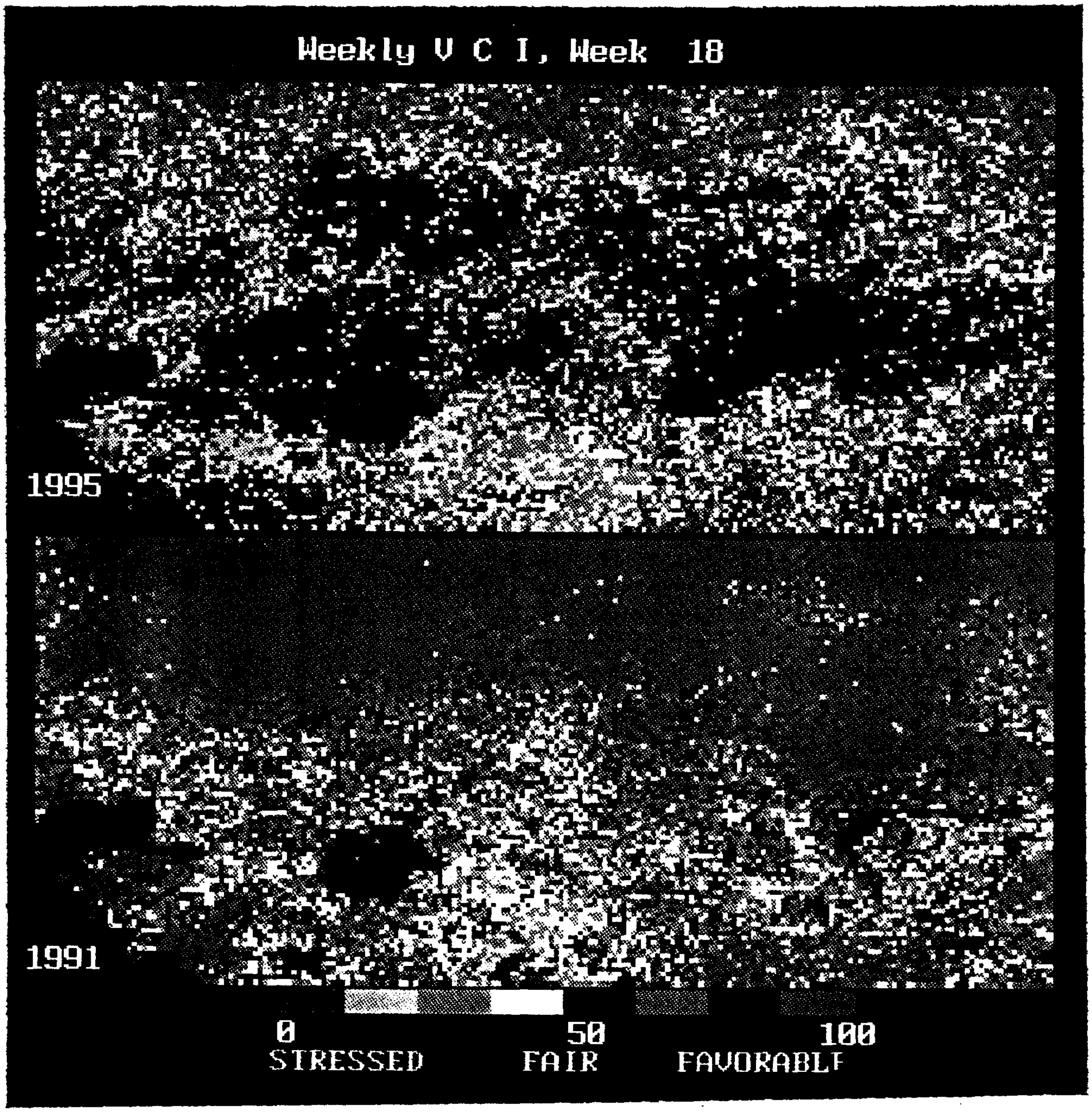


Fig. 31. Vegetation Condition Index for May 1-7 (week 18) 1995 and 1991 for each 16x16 km pixel.

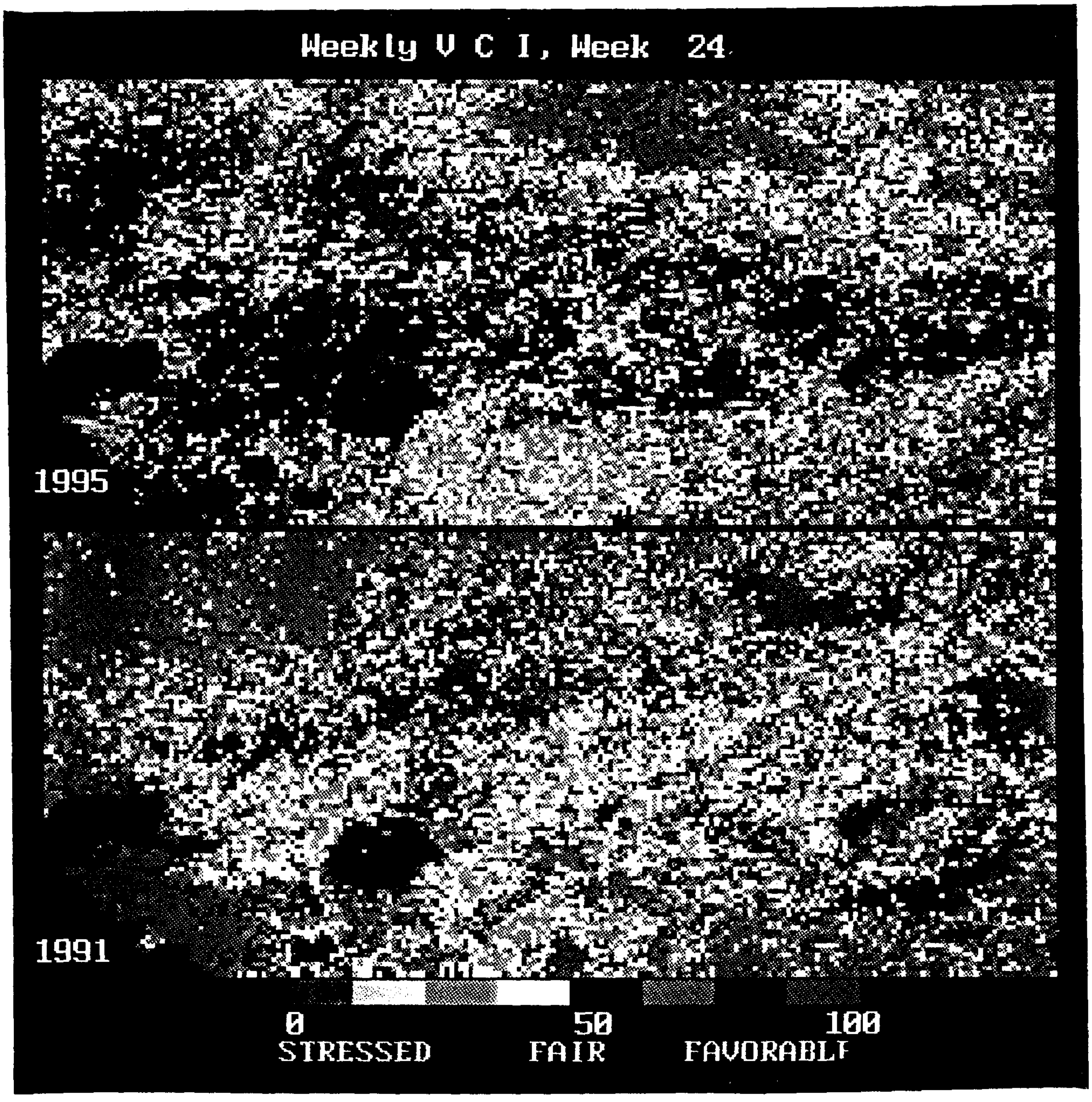


Fig. 32. Vegetation Condition Index for June 12-18 (week 24) 1995 and 1991 for each 16x16 km pixel.

only in a few locations. We should emphasize that June is a most critical month in terms of water requirement for development and productivity of vegetation. These conditions were quite stable if we compare the VCI estimate for the end of June (Fig. 26) with the beginning of July (Fig. 27). There is very little difference between VCI-derived drought intensity and extent.

It is interesting to note that the vegetation conditions at the beginning of the 1991 (unfavorable year) growing season were better than in the 1992 (favorable year). Figure 28 shows that in early May (week 18) 1992 vegetation over a large area of Kazakhstan was under severe stress, while in 1991, vegetation conditions were favorable. However, during May and June, vegetation conditions deteriorated considerably in 1991 and improved in 1992 (Fig. 29). For most of Kazakhstan agricultural areas, vegetation conditions remained unfavorable until the end of the 1991 growing season and favorable for the 1992 season (Fig. 30). these resulted in very low crop production in 1991 and high production in 1992 (Table 2).

5.6.3. The 1995 large-area vegetation conditions

In 1995, we have been monitoring vegetation conditions of Kazakhstan in near real-time. 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 the 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.

From the beginning of the 1995 growing season (week 18, beginning of May) vegetation in majority of Kazakhstan region was under stress (Fig. 31). These conditions remained unfavorable until the time of our report completion in mid-June (Figs. 32 and 33).

We handed out these data regularly to collaborators in Kazakhstan, and also reported the 1995 test assessments at the AID office in Kazakhstan (on May 25) and gave them to the decision and policy makers at the Ministries of Agriculture, Economics, Environment, Science and Technology (on May 26). During our meeting in Jerusalem on July 3 with the Kazah Minister of Environment Mr. Svatoslav Medvedev, we reported our assessments of vegetation conditions in Kazakhstan up to mid-June 1995. We also gave him a PC diskette with the relevant data files, for use in Kazakhstan.

6. Impact, Relevance and Technology Transfer

The results of this project will help Kazakhstan to start using new remote sensing technology for drought monitoring. The delivered hardware, software, proposed concept and methods, will lay the foundation for a new, complete and efficient drought-watch system. This system will be 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 will also 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, will 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 will be, 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 level 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 IBM 486 for data collection and initial processing; image processing hardware and software for data processing, storage and distribution; algorithms for converting satellite radiances into the new Vegetation Condition Index (VCI); algorithms for converting the VCI 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 Russia (Moscow) on November 5-20, 1993 to meet with collaborators Prof. E. Zakarin and Dr. L. Spivak (Kazakhstan) at the Institute for Space Research of Russian Academy of Sciences. The goal of this meeting was to initiate the project, to select hardware and software appropriate for Kazakhstan.

Prof. E. Zakarin and Dr. L. Spivak (Kazakhstan) visited Israel (Beer-Sheva and Sede-Boker) on April 6-20, 1994 to meet with Principal Investigator Dr. A. Gitelson at the J. Blaustein Institute for Desert Research of Ben-Gurion University of the Negev. The goal of this meeting was to introduce the receiving station TELONICS and hand-held radiometers to our Kazakh collaborators and to train them to use the hardware.

Dr. Kogan (USA) visited Russia (Moscow) on August 5-20, 1994 to meet with our collaborator Dr. L. Spivak (Kazakhstan) at the Institute for Space Research of the Russian Academy of Sciences. The goal of this meeting was to discuss and exchange the results obtained during the 1994 field experiments in Kazakhstan and to provide the training and processing of images at the Institute for Space Research.

Dr. A. Gitelson (Israel) visited Kazakhstan (Almaty) on May 20-30, 1995 to meet with entire Kazah team at the Kazah Institute for Space Research . The goal of this meeting was to control the quality of the 1994 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 Kazakhstan (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 Kazakhstan.

Dr. Kogan (USA) visited Israel (Beer-Sheva and Sede-Boker) on June 25-July 9, 1995 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 1994 experimental data, historical and current satellite and ground data, and to discuss the final results, and to write the final report for this project. During this visit we also met with the Kazah Minister of Environment Mr. Svatoslav Medvedev in Jerusalem on July 3, where we reported the main results of this project, presented the current assessments of vegetation condition in Kazakhstan up to mid-June 1995 and handed over a PC diskette with the data files for use in Kazakhstan.

8. Project Productivity

All project goals were accomplished. Scientific principles, hardware and software of non-conventional system which will use NOAA operational polar-orbiting satellites for quantitative assessments of pasture and crop conditions and productivity in Kazakhstan were developed.

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

* calibration of satellite-derived indices versus ground data at experimental sites;

* aircraft remote sensing measurements together with ground observations (despite of the fact that the current economic situation in K is very difficult, our collaborators found it possible to carry out these experiments).

* near real-time monitoring of drought and vegetation conditions in 1995.

9. Future work

This project suggests several immediate tasks for:

* launching a system for receiving and real-time monitoring of drought, and monitoring of crop and pasture conditions and their productivity;

* developing a satellite data base for the entire region of Kazakhstan.

* validating the algorithms for the major crop- and pasture-producing regions of Kazakhstan.

References

Baret, F. and Guyot, G. (1991), Potential and limits of vegetation indexes for LAI and APAR assessment. *Remote Sens. Environ.* **35**:161-173.

Danson, F.M., and Plummer, S.E., (1995), Red-edge response to forest leaf area index. *Int. J. Remote sensing,* **16**: 183-188.

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

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.

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

Goward, S.N., C.J. Tucker, D.G. Dye, 1985. North American vegetation patterns observed with NOAA-7 Advanced Very High Resolution Radiometer. *Vegetation,* **64**: 3-14.

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.

Gray, T.I., D.G. McCrary, 1981: The environmental vegetation index, a tool potentially useful for arid land management. AgRISTARS Report EW-N1-04076 JSC-17132.

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

Holben, B.N., 1986. Characteristics of maximum-value composite images from temporal AVHRR data. *Int. J. Remote Sensing,* **7**: 1417-1434.

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

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. Journal of Remote Sensing,* **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. Drought of the late 1980s in the United States as derived from NOAA polar-orbiting satellite data. *Bul. of the Amer. Met. Soc.,* **76**(5).

Kogan, F.N., 1995b. Application of vegetation index and brightness temperature for drought detection. *Adv. Space Res.* **15**(11): 91-100.

Kunkel, K.E., S.E. Hollinger, F.N. Kogan, 1991. Soil moisture /evaporation/ precipitation feedback: a case study of the 1988 drought. Proceeding of the 10th Conference on Biometeorology and Aerobiology, AMS, September 10-13, Salt Lake City, UT.

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

M.N. Merzlyak and Gitelson, A.A., 1995. Why and what for the leaves are yellow in autumn? On the interepretation of optical spectra of senescing leaves (Acer platanoides L.) *J. Plant Physiol.* **145** (3): 315-320.

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

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

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.

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.

Sellers, P.J., 1985. Canopy reflectance, photosynthesis and transpiration. *Int. J. Remote Sensing,* **6**: 1335-1371.

Townshend, J.R.G., C.J. Tucker, 1981. Utility of AVHRR of NOAA-6 and NOAA-7 for vegetation mapping. Matching Remote Sensing Technologies and Applications, London, Remote Sensing Society, pp. 97-107.

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.

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., and P.J.Sellers, 1986: Satellite remote sensing of primary production. *Int. J. Remote Sens.*, **7**: 1395-1416.

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

van Dijk, A., S.L. Callis, and C.M. Sacomoto, 1986. Smoothing vegetation index profiles: an alternative method for reducing radiometric disturbance in NOAA/AVHRR data. *Photogramm. Eng. and Remote Sensing,* 53: 1059-1067.

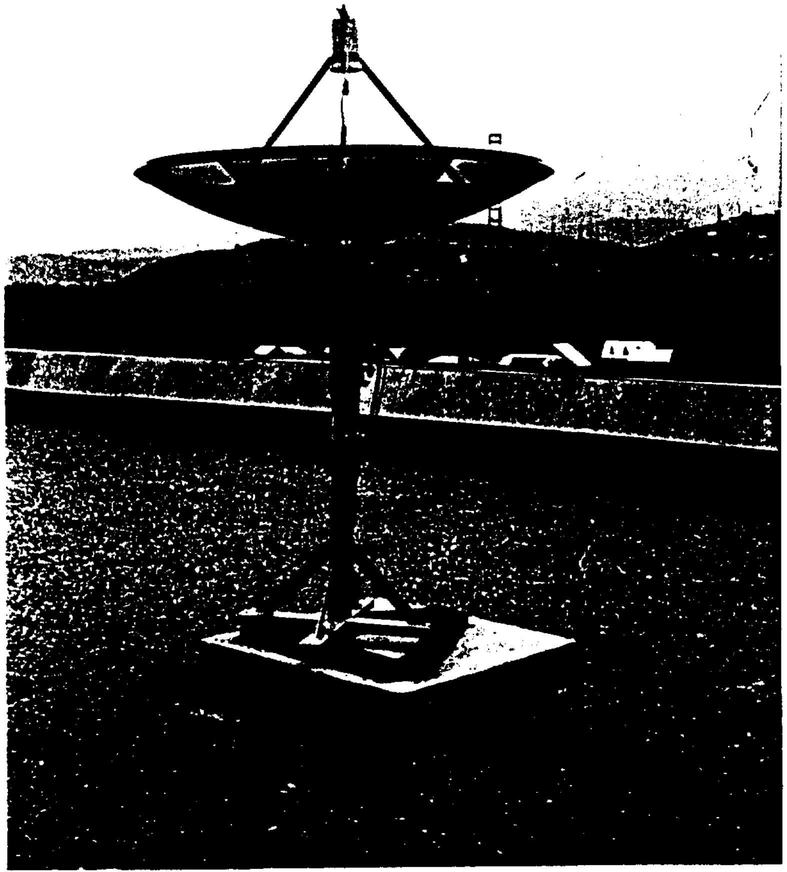
Velleman, P. and D.C. Hoaglin, 1981: Applications, basics and computing of exploratory data analysis. Duxbury Press, 343 pp.

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

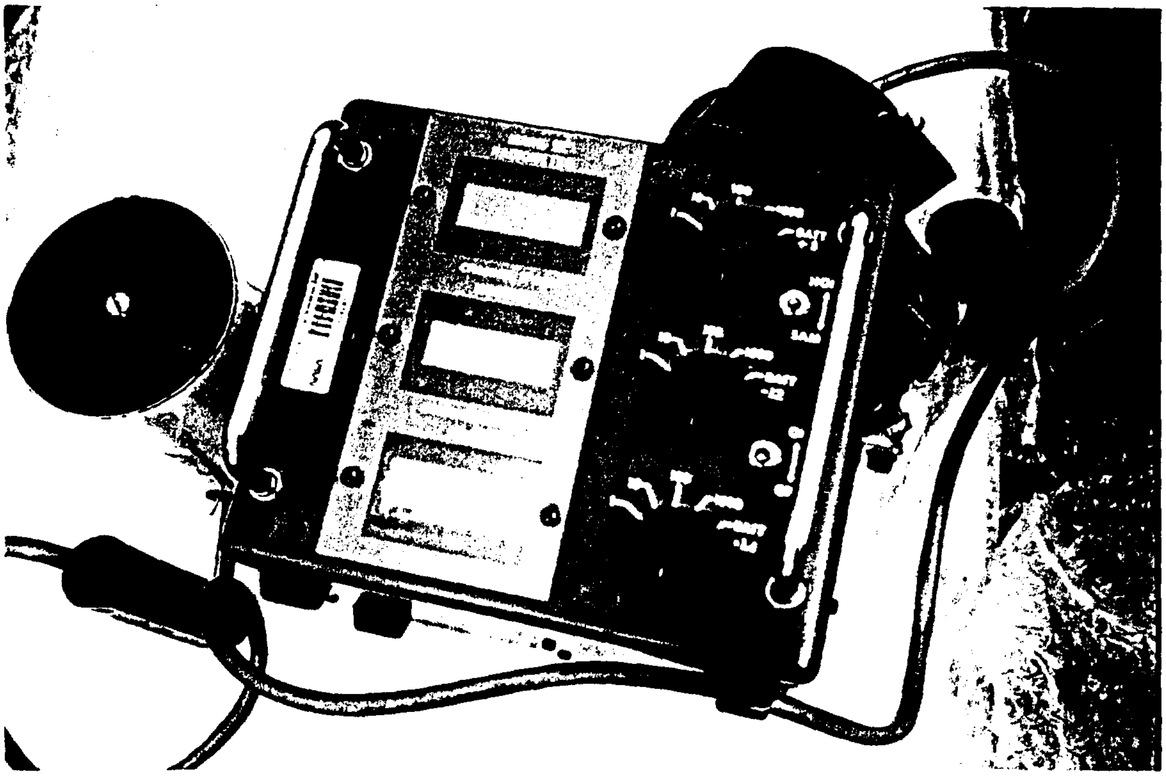
Wilhite, D.A. 1993: Planning for Drought: A Methodology. In Drought Assessment, Management, and Planning: Theory and Case Studies (Ed. D. Wilhite), Kluwer Academic Publisher: 87-109.

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

Appendix A



TELONIX receiving station installed at the roof of the Institute for Space Research, Academy of Sciences of Kazakhstan in Almaty. Antenna for receiving high resolution NOAA/AVHRR data (HRPT format).



NASA designed field hand-held radiometer

Airborne radiometer DPF

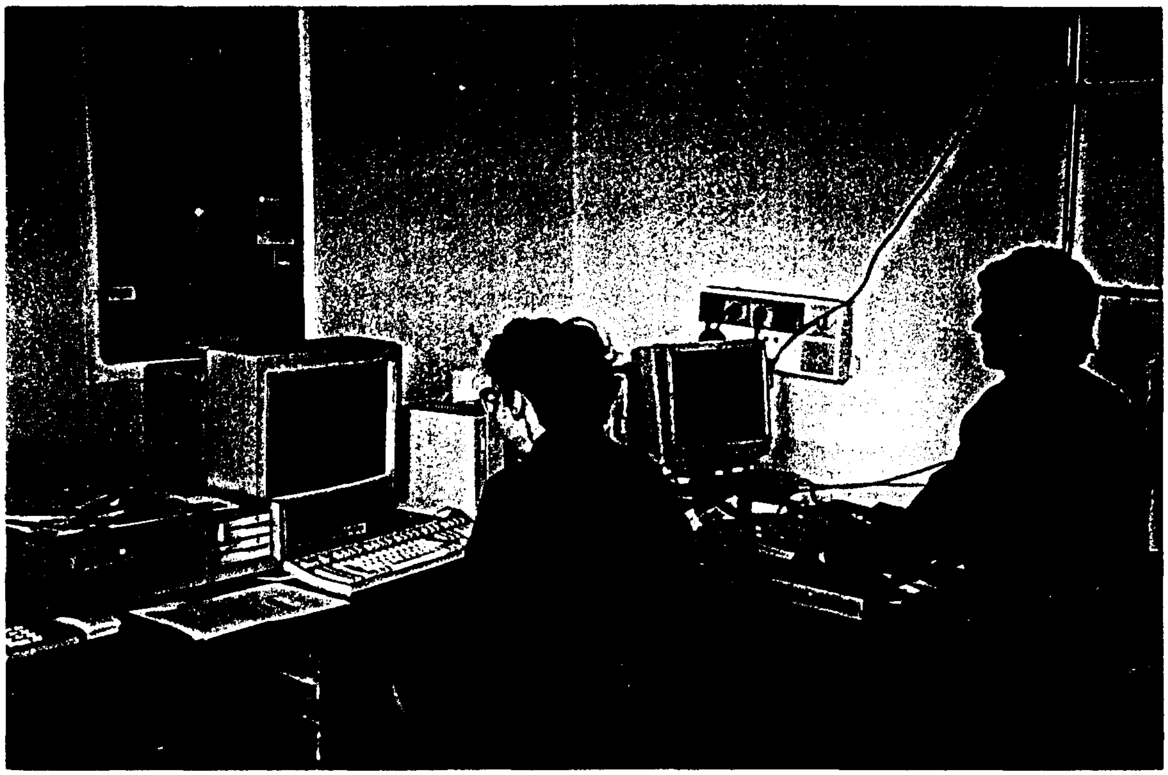


Image processing laboratory. Institute for Space Research, Academy of Sciences of Kazakhstan, Almaty.

Kazakhi and Israeli team members. Almaty, May 1995

Research proposal submitted to AID/CDR for the Central Asian Republics

Estimation of seasonal dynamics of arid zone pasture and crop productivity using NOAA/AVHRR data.

Request for extension

Phase II: Launching the Remote Sensing System

Principal investigators:

Dr. Anatoly Gitelson
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 and Dr. Lev Spivak

Institute for Space Research, Academy of Sciences
Kazakhstan

Phase I has been granted by
US-Israel AID/CDR/CAD program
Grant No. TA-MOU-CA13-056

Beer-Sheva
July 1995

Scientific summary and relevance to development

Kazakhstan agriculture is highly dependent on climate and weather. Only in recent years weather-related variation in total grain production changed from 12 (1991) to 30 (1992) million metric tons. Unfortunately, weather-watch system does not provide enough information about crop and pasture conditions and productivity. The current economic situation in Kazakhstan put additional constrains on conventional observation system for monitoring the environment because the number of weather stations is sharply decreasing and quality of environmental observations is deteriorating.

In 1993 the Agency for International Development (AID) funded the two-year project "Estimation of pasture and crop productivity using NOAA/AVHRR data". During these two years (1993-1995) we developed scientific principles and hardware and software background of non-conventional system which will use NOAA operational polar-orbiting satellites for quantitative assessments of pasture and crop conditions and estimating their productivity in Kazakhstan.

The HRPT station and PC hardware is able to collect, process and store NOAA polar-orbiting satellite data over Kazakhstan region. The developed algorithms will convert these data into the VCI and into crop and pasture characteristics. However, the created data bases were developed and the algorithms were validated only in principal ecological zones and for test sites.

We suggest to extend the project for one more year in order to:

* *launch a system for receiving* NOAA/AVHRR data *and real-time monitoring drought and crop and pasture conditions and productivity;*
* *develop satellite data base for the entire Kazakhstan.*
* *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.*

Strengthening Scientific and Technical Capacity of Kazakhstan

The results of this one-year extension will help Kazakhstan to start using new complete remote sensing system for real-time drought-watch and monitoring crop/pasture conditions and productivity. This system will be the main contributor to an early warning crop and pasture hazardous condition assessments and prediction of agricultural production. The finding of this extension will also 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, will help to develop 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.

Description of the research plan

For a period of one year the project team plans

1. To launch a system for receiving NOAA/AVHRR data and real-time monitoring drought and crop and pasture conditions and productivity.

The signal obtained from NOAA-14 satellite will be mapped, geometrically corrected, sampled from 1 to 16 km and 1 to 7-day composite. The data will be used together with data base for calculating the Vegetation Condition Index which in turn will be used for detecting droughts and monitoring its development, extend, duration and impact on vegetation. The final results will be weekly maps of this product provided to policy and decision makers.

2. To develop satellite data base for the entire Kazakhstan.
This data base includes
* real time observed radiances in visible and near infra-red channels and NDVI;
* historical NDVI and VCI data for each 16 by 16 km pixels and real time VCI data.

3. To validate the algorithms for major crop- and pasture-producing regions of Kazakhstan.

The attempt will be made to calibrate the VCI data against crop/pasture yield and production for main administrative regions (oblast).

4. To use NOAA/AVHRR thermal channels for improvement of the reliability of the developed algorithms.
These channels are known to improve the accuracy of estimating of earth surface characteristics especially the productivity of vegetation.