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USSR: The Impact of Recent Climate Change on Grain Production

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USSR: THE IMPACT OF RECENT CLIMATE CHANGE ON GRAIN PRODUCTION

SUMMARY

1. During the past 15 years a significant fluctuation, which strongly aided grain production, occurred in the climate of the Soviet grain belt. The severe drought of 1975 may have marked the end of the favorable climate trend and signaled a return to the harsher conditions of the early 1960s.

2. The climate fluctuation that occurred between 1960 and 1974 appears to be an anomaly, resulting in an increasing flow of maritime air from the North Atlantic that generally caused

- increased precipitation,
- warmer winters, and
- cooler summers.

The net effect was to move the moister northern climate southward about 2 degrees of latitude, pushing back the desert and nearly doubling production in the new lands area of Kazakhstan.

3. Between 1962 and 1974, total grain production in the USSR increased 6.8 million metric tons annually on the average.[1] It is estimated that about half of the increase in grain production since 1963 has been caused by the more favorable climate.[2] The impact of climate, however, has varied greatly:

- Most of the improvement occurred during 1969-73.
- The impact was largest in the southern fringes of the grain belt, east of the Urals. There was little or no impact in the normally moist areas such as the Baltics and Belorussia.
- Because it is grown in areas with marginal rainfall, the impact on spring grains production was much greater than the impact on winter grains.

1. Throughout this publication, trends have been calculated using least squares regression.
2. Data limitations and the subjective nature of some of the available evidence do not allow a quantitative confidence interval to be set on the relative affect of climate. However, it is judged that the effect of climate is between 40% and 60%.

4. Three projections of average annual grain production have been made for 1976-80, based on different climatic assumptions:

> **Projection 1** – the "best" case – assumes that the extraordinarily favorable climate of 1970-73 prevails. This suggests an average annual crop of 242 million tons.
>
> **Projection 2** – a recent average – is based on the climate of 1962-75. Accordingly, an average crop of 223 million tons is projected.
>
> **Projection 3** – the "worst" of the recent past – is based on the climate of 1962-65 and yields an average projected crop of 200 million tons.

5. Climate cannot yet be forecasted reliably, but available evidence indicates that the last projection is the most realistic one, putting the Soviet grain goal of 217 million tons out of reach. An output of 200 million tons falls about 25-30 million tons short of estimated annual requirements during 1976-80. If the Soviets choose to cover the deficit by imports, purchases of foreign grain would match those following the disastrous grain harvests of 1972 and 1975. More likely, the Soviets, as they have done in the past, will reduce their requirements in a year of a major downturn in grain output by lowering their short-run goals for meat output and livestock inventories.

6. The 1975 drought does not appear to be an aberration but part of a drier trend, which can be expected to occur with varying degrees of intensity for some time to come. During the 1960s the Northern Hemisphere was cooling. This period was marked by hemispheric changes such as the Sahelian drought, failures of the Indian monsoon, increasing polar ice, and increased rainfall in the Soviet grain belt. Recently, the cooling trend has reversed, and the Northern Hemisphere now is warming. Rains have returned to the Sahel and India, and rainfall has decreased in the Soviet grain belt. Changes of this magnitude involve the exchange of large amounts of energy affecting climate over many years.

7. An important assumption underlying our estimated average annual production of 200 million tons concerns the role of "nonweather" factors in changing grain yields. We have explicitly assumed that the trend in the usage of fertilizer and other yield-enhancing factors – referred to as "technological improvements" – during 1961-74 will continue through 1980. An increased priority for grain production could result in an acceleration in application of existing technology on grain at the expense of other crops during the next five years. As a result, a step-up in the rate of growth in usage of fertilizer, for example, could alter upward the projection for 1976-80.

DISCUSSION

Introduction

8. The world's climate and the possible effect of a change in climate on food production is receiving increased attention. In particular, the drought and subsequent famine in the Sahelian zone of North Africa during the late 1960s and early 1970s has focused world attention on the implications of climate change. According to evidence gathered by climatologists, the Northern Hemisphere has been cooling since the mid-1940s. This cooling may have been responsible for the widespread failure during the 1960s of the rain-producing monsoons in the grain-growing regions that lie south of the tropical deserts.

9. In the USSR, a grain crop shortfall in 1972 and subsequent massive imports drew attention to the potentially precarious situation some grain-producing countries in the North Temperate Zone might face because of climate fluctuations. Bounded to the north by cold temperatures and to the south by deserts, the grain-growing region of the USSR has a high potential for disastrous weather should the boundaries of these unfavorable climates shift.

10. Little has been done to evaluate the effect that this climate change has had on food production in the temperate latitudes. This report (1) discusses the nature of climate and climate change, (2) uses detailed meteorological data to measure changes in the climate in the USSR grain belt, and (3) estimates the impact of the climate change on grain production since 1962.

Background

The Nature of Climate

11. Climate is the weather of a region averaged over some period of time.[3] The whirling boundary of air that encircles the globe between the cold polar air

3. Climate is weather on a longer time scale. For example, daily mean temperature is used to describe weather while mean temperature for a decade or longer is used to characterize climate. Both are averages and both change with time. In regions where the water supply is critically low, seemingly small changes in weather can have large consequences on food production, and the difference between a 10-year drought (a weather phenomenon) and a climatic change is only semantic.

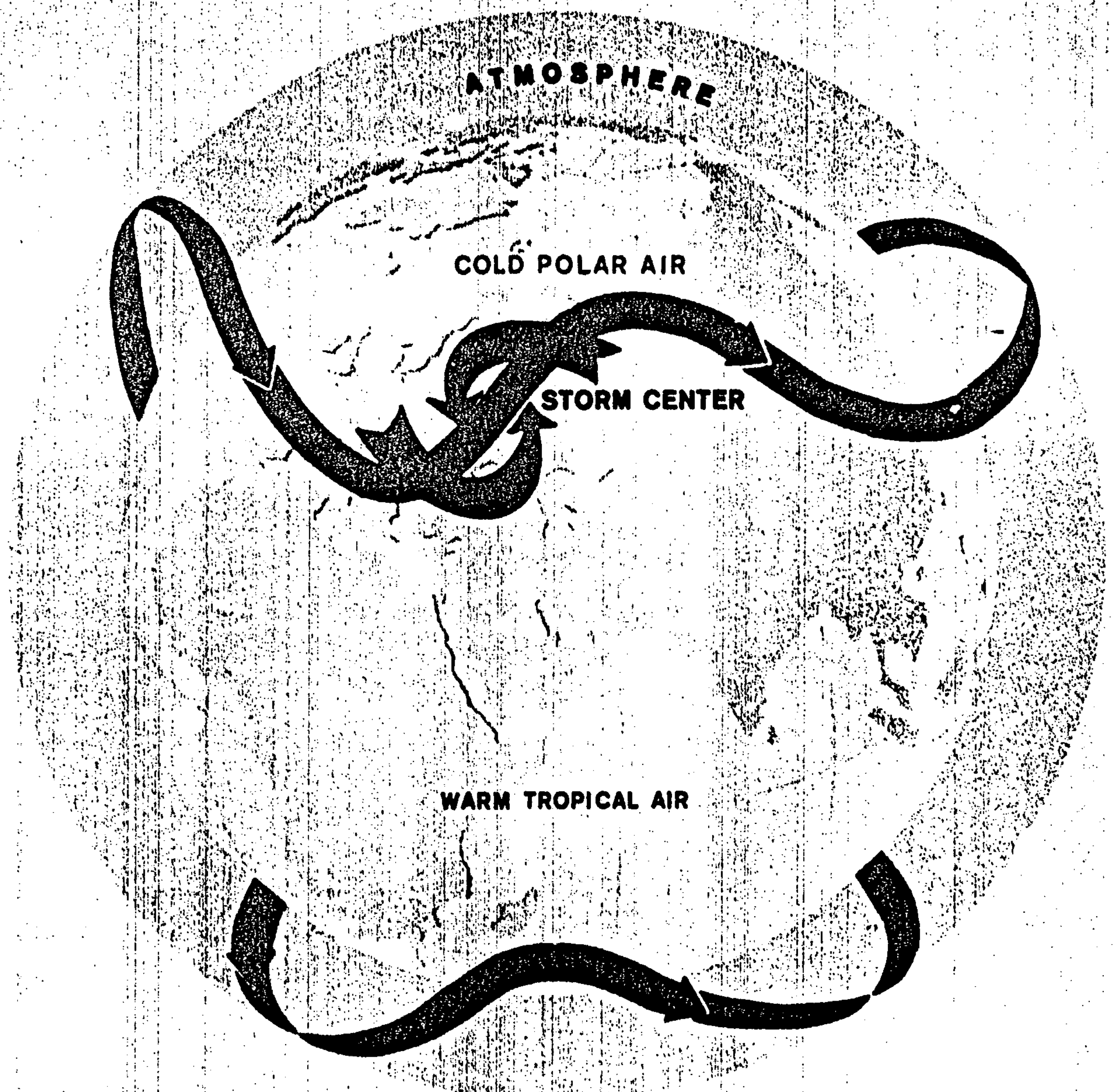
Disagreement over the definition of climate has frequently been over the length of time – ranging from 10 to more than 30 years – necessary to establish norms. For example, the World Meteorological Organization uses the past three complete decades to determine an area's climate, while the Department of Defense uses 10 years in its new worldwide meteorology data base. None of these definitions ignore the ice ages of the past but rather assume that the changes are so slow that the climate during the next 10 to 30 years will be much like that of the last 10 to 30 years.

In this publication climate means weather averaged for a year or more. This definition makes no assumption about the stability of climate.

and warm subtropical air marks the location of the storm systems and weather fronts (see Figure 1). The size of the circumpolar vortex, the dome of cold air covering the polar regions, is related to the state of the climate – temperature

The Circumpolar Vortex

Figure 1



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and precipitation. As the Northern Hemisphere cools in the winter the circumpolar vortex expands, cooling the temperate latitudes and moving the hemispheric weather patterns southward. In the summer it contracts, allowing warmer air to move north from the subtropics.

12. Waves that form along this boundary cause large masses of cold air to splash southward into the warm subtropical air, and warm air is forced northward in spinning storm systems that move eastward through the temperate latitudes bringing anything from cloudy weather and drizzle to severe storms with floods and damaging winds. The shape, size, and number of these waves depend on the size of the polar vortex, the temperature differences between the pole and the equator, and the topography over which the air flows.

13. Climate in the USSR grain region is further controlled by the stationary pressure systems that form over the large land mass of Siberia and the North Atlantic Ocean. Winters in the grain region are dominated by a Siberian high pressure system and a North Atlantic low pressure system causing the wind to flow from the southwest. This air originates in north Africa and southeastern Europe and is therefore dry. The storms bringing moisture from the North Atlantic must overcome this gentle push to the north which makes it difficult for precipitation to get into the southeastern portion of the Soviet grain region. Summers have just the opposite pressure pattern, with a Siberian low and a North Atlantic high bringing air from the northwest.[4] Because almost all of the water in the grain regions comes from the North Atlantic, summer is the season of maximum rainfall for most regions. This air dries out as it moves east and south, dropping less and less precipitation as it goes.

Climate Classification

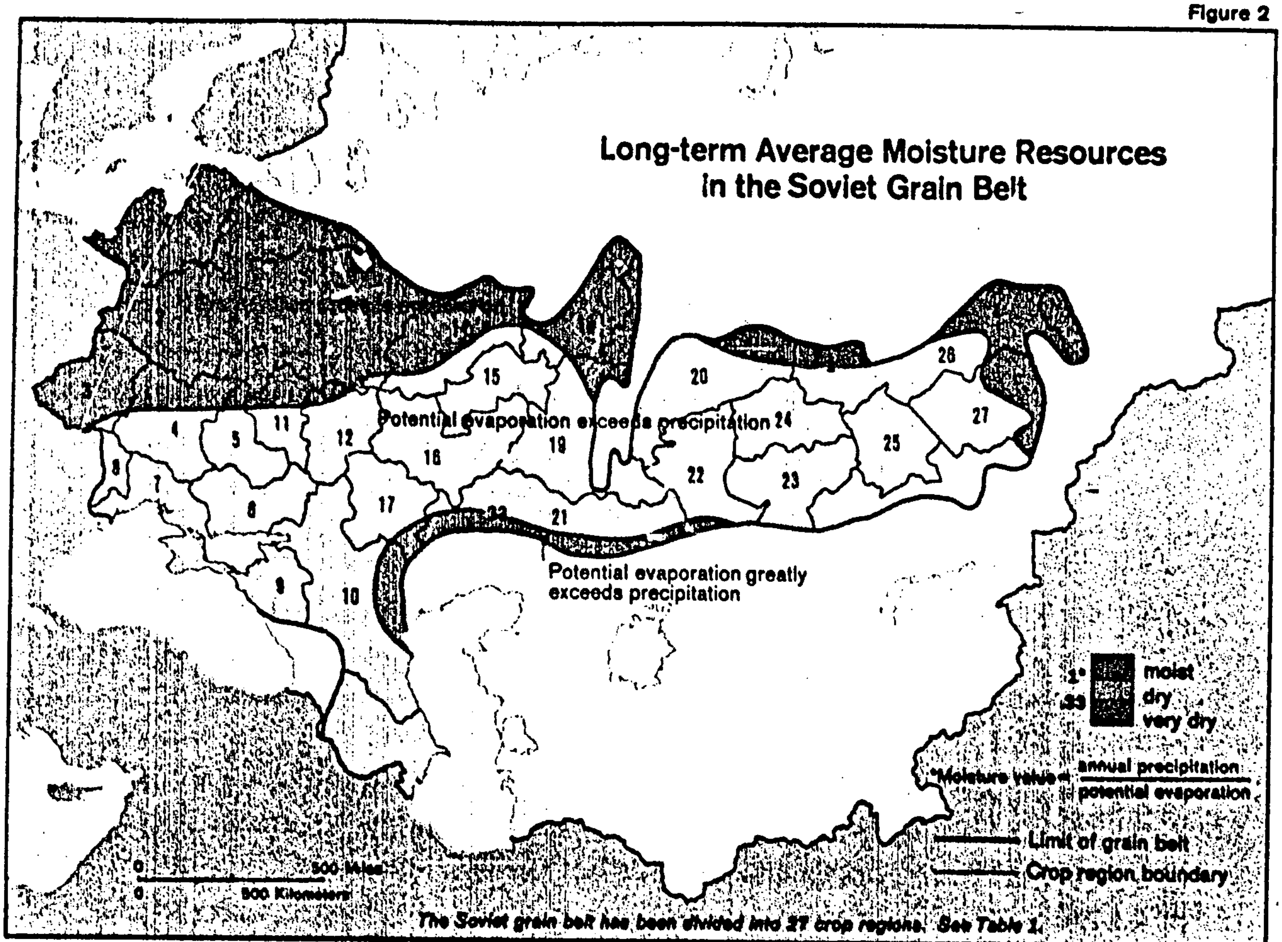
14. An area's climate is commonly classified by average annual precipitation and temperature. It is therefore possible to calculate values for a given area and to identify a climate type – desert, steppe, moist-continental, and the like – for a single year for any area. For example, Koppen, who derived the most widely used classification system, defines a moist-continental climate as one where (1) the average temperature is below freezing for at least one month, (2) the average temperature exceeds 10°C for at least one month, and (3) annual precipitation exceeds annual evaporation potential.[5] The entire Soviet grain belt qualifies with regard to temperature, but in many places evaporation potential exceeds precipitation, making the normal climate a steppe rather than moist-continental

4. Oceans have relatively stable temperatures throughout the year while land surfaces change temperature rapidly and have extreme temperature differences between summer and winter. From January to July the North Atlantic varies only 8° Celsius (C) while north-central Siberia varies more than 60°C.

5. The Koppen climatic classification system is discussed in G.T. Trewartha, *An Introduction to Climate*, New York, 1954, p. 227.

(see Figure 2).[6] If evaporation potential exceeds precipitation by a large enough margin, a steppe becomes a desert. Generally, excluding irrigation, small grains grow well in a moist-continental climate, with difficulty in a steppe, and not at all in a desert.

Figure 2



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Climate Change

15. Climate is constantly changing and temperature is usually used to measure the change. Although the difference between an ice age and a mild period may be only a few degrees Celsius in the average global temperature, the result is large climate changes over vast areas. Cooling is associated with expansions of the polar vortex and a tendency to southward migration of climate patterns. This shortens growing seasons in northern regions, brings rain to the northern edges of deserts, and dries the land south of the deserts.

16. Simple global climate fluctuations have complex local effects. As the polar vortex expands, its wave pattern changes; air temperature and wind patterns affect ocean temperatures and currents that in turn affect the climate. In addition,

6. In such regions streams cannot originate; rivers flowing into these regions lose, rather than gain, water.

mountains alter the flow of winds; not only do the winds move north or south but also the precipitation patterns of these winds may change depending on the topography. Although the north to south – or zonal – climate changes may be important, the east to west – or meridional – changes are nearly always more important.

17. Local yearly, daily, and hourly variations in temperature and precipitation are much greater than the 10- to 100-year climatic variations. A long-term change in climate may result in a slightly cooler, more moist climate in a specific region, but it may also increase the variability in temperature and precipitation. As a result, crop-damaging hot, dry years may occur much more often than they did prior to the long-term cooling. A shift in wind direction may be associated with a general hemispheric cooling but cause a large area to become warmer. The effect of local terrain and the complex interactions of air, water, and land make generalized predictions difficult.

Climate Change in the USSR

18. During the past 15 years a significant fluctuation occurred in the climate of the Soviet grain belt that affected production. Examination of daily temperature and precipitation data for approximately 1,000 reporting stations scattered across the Soviet grain belt suggests that while the Northern Hemisphere was cooling, the climate in this area generally has become warmer and wetter.[7] The slight warming in the Soviet grain belt was caused by a shift in wind patterns. Although sharp variations occurred among grain-growing regions from year to year, the trend in the USSR resulted from increasing flows of maritime air from the North Atlantic, which increased precipitation and caused warmer winters and cooler summers (see Figures 3 and 4). Between 1962 and 1975, average annual precipitation in the Soviet grain belt increased by 44 millimeters, or about 10%, in comparison with the

7. Detailed meteorological data have been available from the USSR since the mid-1940s. Moreover, data for many stations extend back to the mid-19th century. Summaries of these data, largely since the 1940s, form the long-term averages used in this publication. Precipitation and temperature data for individual weather stations in the USSR are broadcast two or four times daily by Soviet meteorological radio stations. As a member of the World Meteorological Organization, the USSR shares such information with foreign countries. These data are part of a worldwide standardized system that insures consistent quantitative measures of weather parameters from year to year. There are now approximately 1,000 stations located in the Soviet grain region. These data, when summarized, serve as the base for analyzing crop conditions, studying climate changes, estimating Soviet grain production, and evaluating the effects of changing technology on Soviet farms. Until 1965, average values of temperature, precipitation, and soil moisture for the grain belt were computed by hand; since then they have been routinely processed by computer on a daily basis. The differences in processing could result in small-scale, random errors for individual crop regions prior to 1966, but country-wide annual averages would be unaffected by the method used to calculate the averages.

Figure 3

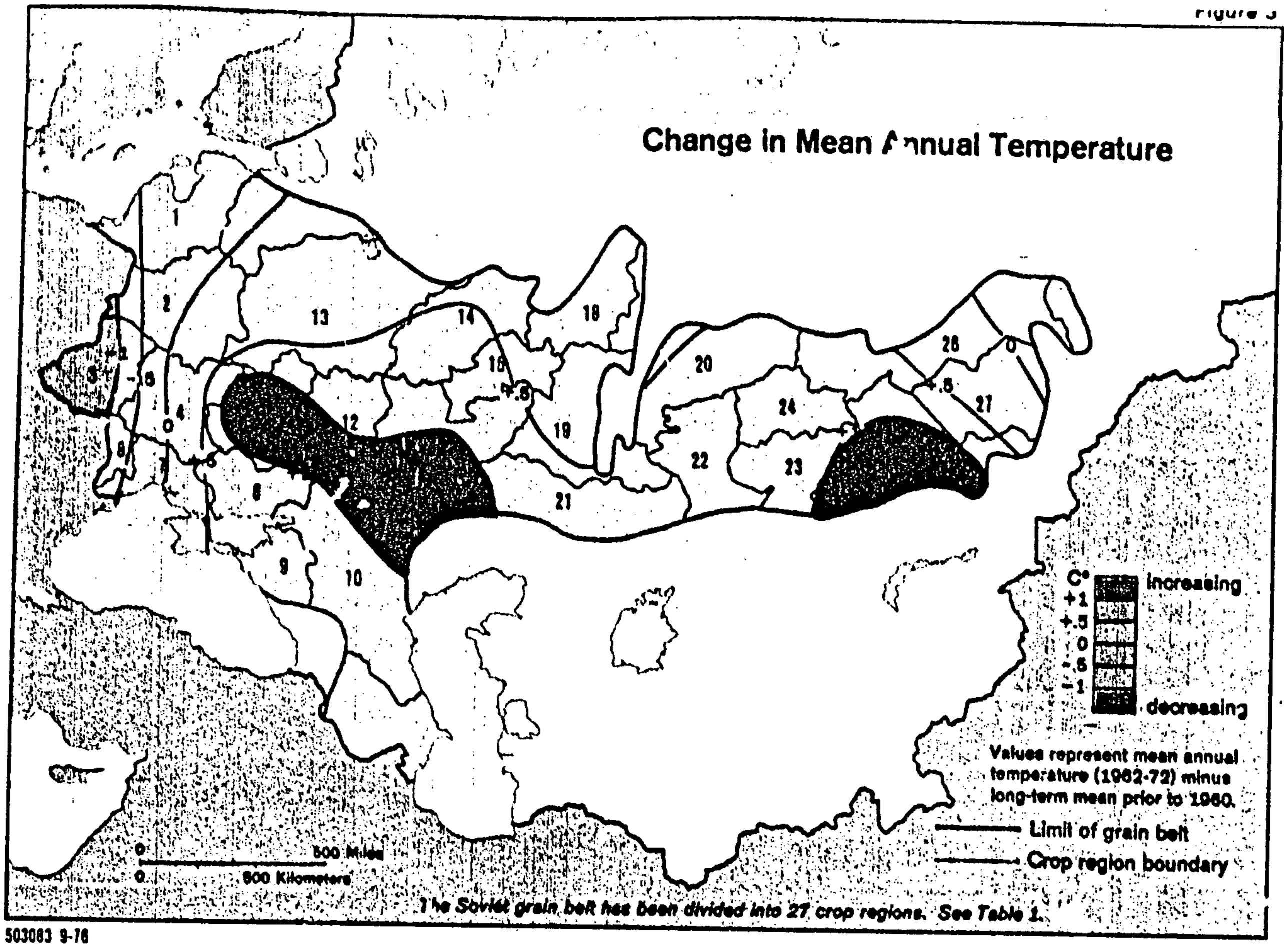

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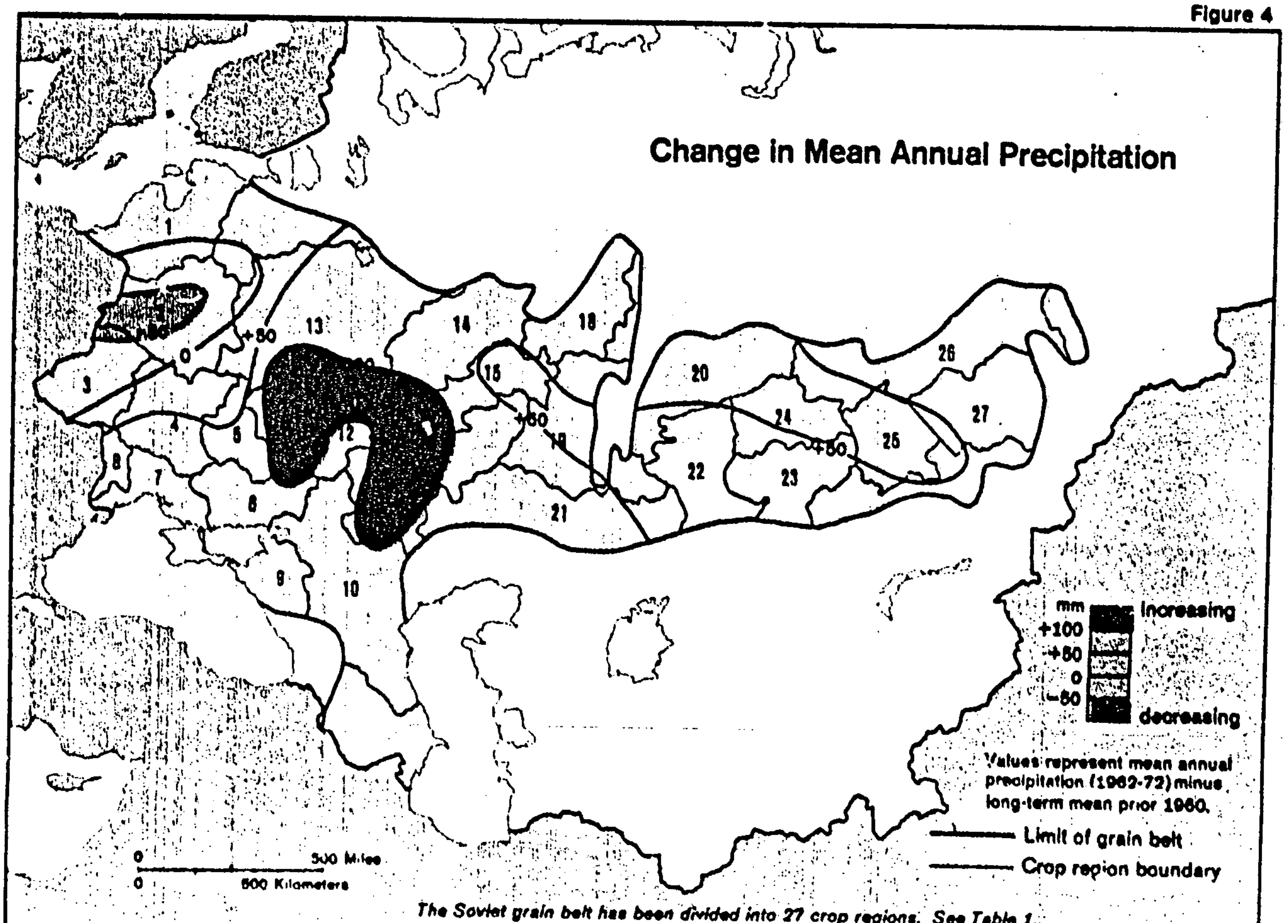
Figure 4



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long-term average prior to 1960, while average temperatures rose about three-fourths of a degree Celsius.[8] Moreover, the southward shift of the polar vortex during this period appears to have moved the moister northern climate southward about 2 degrees of latitude, pushing back the desert and increasing agricultural production in the new lands area of Kazakhstan and Central Asia.

19. Three periods are used to discuss recent Soviet climate:

Pre-1960 – Climate average of all available data prior to 1960 is used to establish a benchmark for comparison of subsequent events.[9]

1960-68 -- This was a period of transition from the dry, unstable early 1960s to the moist, stable early 1970s.

1969-74 -- A period of unusually moist, stable climate that was favorable to grain production.

This last period was unusually moist in the steppe regions of the grain belt. The cycle of alternate moist and dry years that is common in these regions was absent. The dryness in 1975 combined with other global climate changes may indicate that the aberration of dependable moisture in this normally dry region has ended.

20. The choice of these periods was based on both climate events and on data limitations. Detailed data have been available only since 1960 for precipitation and since 1962 for temperature, marking the earliest dates that yearly analysis was possible. The break between 1968 and 1969 was chosen because of Soviet climate patterns and associated hemispheric climate events. The final year, 1975, was separated because of its sharp departure from recent Soviet climate. These periods are used whenever possible in future discussion in this report. Lack of temperature data will at times cause 1960 and 1961 to be omitted from the second period.

21. Changes in the number of crop regions falling into the various climate types is a rough gauge of climate change. In the early 1960s the number of regions classified as either steppe or desert ranged from 3 to 16 with an average of 11 (see Table 1). In contrast, from 1969 through 1974 the average number of regions

8. Long-term average precipitation prior to 1960, weighted by recent sown areas of all grains, is 432 millimeters per year. A difference of 44 millimeters represents 2.1 standard deviations for a sample size of 14.

9. No attempt is made to establish this period as "normal." Its value is that it has a significantly longer period of record.

Table 1

Koppen Climate Types, by Crop Year[1]

Crop Region	Mean Annual Precipitation (mm)	Long-Term Mean	1960[2]	1961[2]	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Total steppe and desert regions		9	12	10	16	16	3	10	6	3	8	2	0	2	5	1	2	13
Very Wet																		
13 Central Region	733	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
9 Krasnodar Kray	650	H	S	S	H	H	H	H	H	H	H	H	H	H	H	H	H	H
3 West Ukraine	616	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
18 Northwest Urals	612	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Steppe and desert regions		0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wet																		
11 West Black Soil Zone	597	H	H	H	H	S	H	H	H	H	H	H	H	H	H	H	H	H
14 Volga-Vyatsk Region	583	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
1 Baltics	579	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
2 Belorussia	576	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
4 North-Central Ukraine	574	H	H	H	H	S	H	H	H	H	H	H	H	H	H	H	H	H
5 Northeast Ukraine	559	H	H	H	S	S	H	H	H	H	H	H	H	H	H	H	H	S
12 East Black Soil Zone	558	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
15 Upper Volga	543	H	S	H	H	H	H	H	H	H	H	H	H	H	H	H	H	S
8 Moldavia	534	S	S	H	S	H	H	H	H	S	H	H	H	H	H	H	H	H
6 East Ukraine	511	S	S	H	S	H	H	S	H	H	H	H	H	H	S	H	H	S
Steppe and desert regions		2	3	0	3	3	0	1	0	1	0	0	0	0	1	0	0	3
Dry																		
16 Middle Volga	488	H	S	S	S	S	H	H	H	H	H	H	H	H	H	H	H	S
10 Northeast Caucasus	481	S	H	S	S	S	H	S	H	H	S	S	H	S	S	H	H	S
20 Northeast Urals	481	H	H	H	S	S	H	S	H	H	H	H	H	H	H	H	H	S
7 South Ukraine	469	S	S	H	S	S	S	S	S	H	S	H	H	H	S	H	S	S
19 South Urals	455	H	H	S	S	S	H	H	H	H	H	H	H	H	H	H	H	S
17 Lower Volga	433	S	S	S	S	S	H	S	S	S	H	H	H	H	S	H	H	S
26 West Siberia	428	H	H	H	S	S	H	H	H	H	H	H	H	H	H	H	H	H
27 Altay Kray	414	H	H	H	S	D	H	H	H	H	S	H	H	H	H	H	H	H
Steppe and desert regions		3	3	4	8	8	1	4	2	1	3	1	0	1	3	0	1	6
Very Dry																		
24 North Kazakhstan	380	S	S	S	S	S	H	S	H	H	S	H	H	H	H	H	H	H
23 Tselinograd Oblast	348	S	S	S	S	S	H	S	S	H	S	H	H	H	H	H	H	S
22 Kustanay Oblast	341	H	S	S	S	S	H	S	S	H	S	H	H	H	H	H	H	S
25 Pavlodar Oblast	327	S	S	S	S	D	S	S	S	H	S	H	H	H	H	S	H	S
21 West Kazakhstan	316	S	S	S	S	S	S	S	S	S	S	S	H	S	S	H	S	D
Steppe and desert regions		4	5	5	5	5	2	5	4	1	5	1	0	1	1	1	1	4

1. To more closely align climate and crop production, annual averages were computed for crop years (October through September) rather than for calendar years. For this table, H is moist-continental, S is steppe, and D is desert.
2. No temperature data are available for 1960 or 1961. To compute the climate type, the average temperature for 1962-75 was used.

classified as steppe or desert has been only 2 (see Appendix A). There was a sharp departure from this recent trend in 1975 when 13 of the 27 regions qualified as either steppe or desert climates. Not since the drought of 1963 had any crop region been classified as a desert nor had there been 13 or more crop regions that were too dry to be classified as moist- continental. Thus, the climate of 1975 would seem to fit better in the early 1960s than the mid-1970s.

22. In comparing the climate since 1960 with the long-term average, two points stand out. First, with a few exceptions, there was a steady improvement in the climate of the Soviet grain belt between 1960 and 1970. Second, the climate of the late 1960s and early 1970s was more of an aberration than was the climate during the early and mid-1960s.[10] Viewed alternatively, 1975 does not indicate unusual dryness when compared with the long-term average precipitation for the grain belt (see Table 2). Rather, the unusual climate in the USSR grain region occurred in 1969-74, as it did in many other parts of the world.

Effect of Climate Changes on Grain Production[11]

23. Natural conditions in the USSR are generally unfavorable to the growth of grain; both temperature and precipitation, acting alone and in combination, limit the grain-growing region (see Figure 5). North of 60° north latitude the summer temperatures are too cool and the growing season too short for grain. South of the 50° and east of the Urals, insufficient moisture prevents grain growing except under irrigation. The southern movement of the climate during the 1960s and early

10. The long-term average number of steppe and desert regions is 9 while the average for 1969-74 was only 2.0.

11. Both winter and spring grains are grown in the USSR. Because of their differing needs they are usually grown in different areas, but both types of grain have some requirements in common. Winter grains, which are planted in October, lie dormant during the winter, are harvested in June-August, have higher yields than spring grains, and are usually chosen in regions where both types can be grown. Winter grains do not require a long summer growing season and can therefore be grown farther north than can spring grains. Winter grains are restricted to the western half of the grain belt because winter soil temperatures in the east are too low, causing winterkill of the dormant plants. (Critical soil temperatures at the depth of the tillering mode (three cm) for winter wheat is -16°C and for winter rye is -20°C.)

Spring grains have a different problem, since almost all of them are grown in moisture-deficient regions. Most small grains grow best when soil moisture is approximately half the maximum – about 100 millimeters – and yields will be reduced if more or less moisture is present. Although excess moisture frequently affects winter grains in the extreme northwest, it is unusual in the spring grain regions where increased precipitation generally means increased yields, and drought is the major problem. Both long periods of low soil moisture and sukhoveys (hot, dry easterly or southeasterly winds to 8 to 50 kilometers per hour and relative humidities below 30%) take their toll in various amounts each year. Damage to plants is usually quick and irreparable, but its magnitude depends on crop variety, phase of development, soil moisture, and sukhovey intensity.

Table 2

USSR: Total Precipitation for Grain Region[1]

Year (Oct-Jul)	Precipitation (mm)	Years Averaged	Mean (mm)
Pre-1960	349	All years available prior to 1960	349
1960	310		
1961	343		
1962	309		
1963	277		
1964	420	1960-68	354[2]
1965	337		
1966	413		
1967	377		
1968	396		
1969	387		
1970	494		
1971	440		
1972	391	1969-74	434[2]
1973	440		
1974	454		
1975	324	N.A.	324

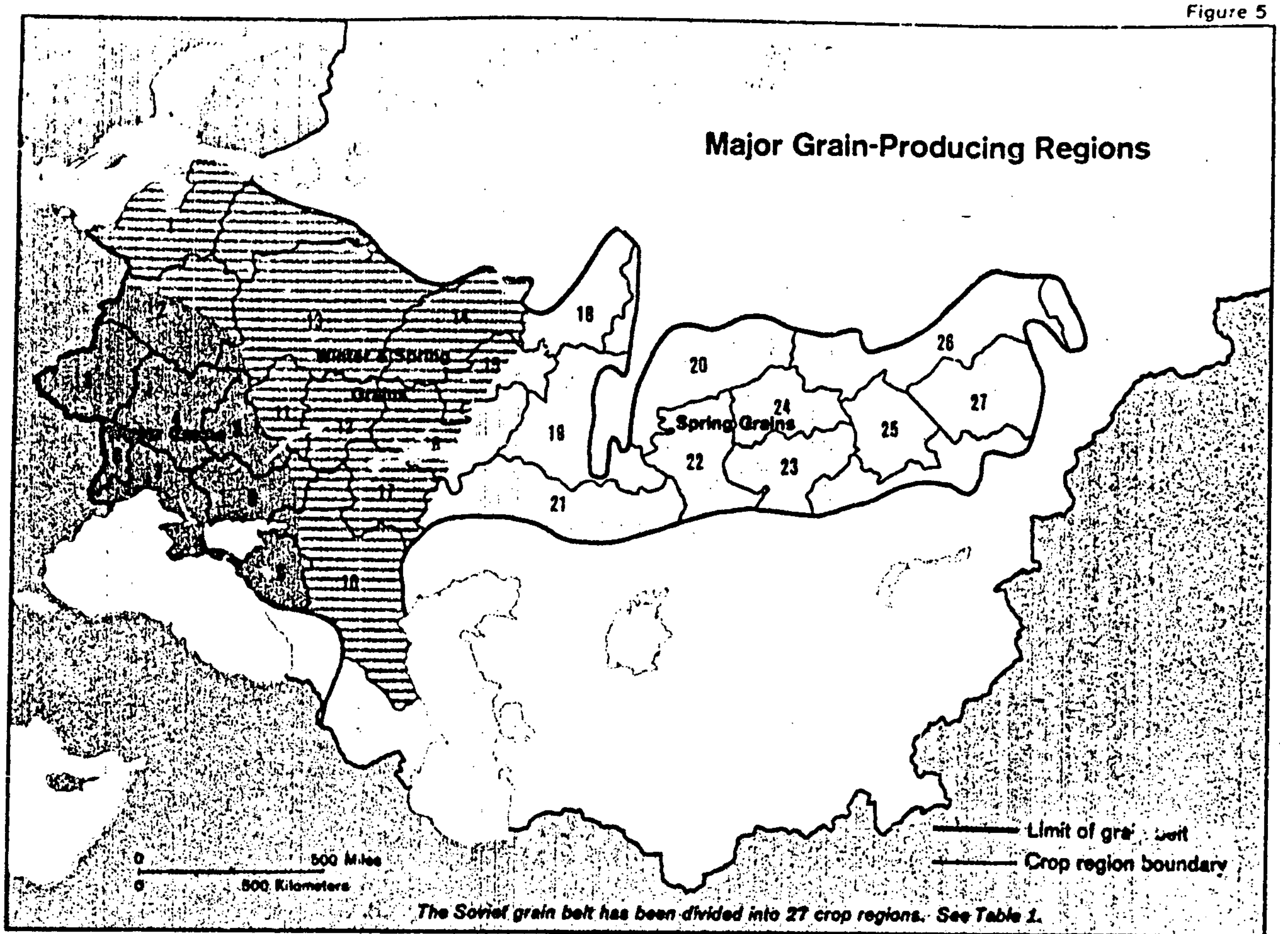
1. Weighted by 1973 area sown to all grains.
2. A t test analysis of these two means indicated that there is less than 1 chance in 100 that these two periods are part of a common population and less than 1 chance in 1,000 that the mean from 1969-74 is part of the population prior to 1960. The mean for 1960-68 is not significantly different from the mean prior to 1960. The value of t for this test is less than 1/5 the value necessary for significance at the 10% level.

1970s substantially boosted Soviet grain production, particularly in the spring wheat area along the southern fringes of the grain belt east of the Urals.

24. To measure the impact of climate change on grain production, we have used spring and winter wheat data as a surrogate for all grain. This avoids data problems arising from changing shares in sown area over time among grains with different yields. Wheat is the most important food grain in the Soviet Union, constituting nearly 90% of the food grain production and about half of total grain production.[12] Moreover, wheat is grown both as a winter and spring grain in the same regions as other important winter and spring grains, and it reacts to the

12. Because of its importance, wheat yields and production data are more consistent and more complete than are data for other grains.

Figure 5



The Soviet grain belt has been divided into 27 crop regions. See Table 1.

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weather in the same way that other grains do.[13] Using wheat yields as an indicator allows 99% of the variance of all winter grain yields and 80% of all the spring grain yields to be accounted for. In general in the Soviet Union, statements about wheat yields can be extended to other grains grown during the same seasons.

25. The impact of the climate change since 1962 on grain yields was estimated by models constructed to calculate winter and spring wheat yields using weather variables – average monthly temperatures, precipation, and soil moisture – and multivariate regression analysis.[14] The variance in grain yields is assumed to come from two sources: weather and technology.[15] Local differences in soil types are assumed to have no bearing on changes in yields over time.[16] The models explain

13. Winter grains include winter wheat, rye, and some barley. Spring grains include wheat, rice, oats, and most of the barley. Corn is normally referred to as a summer crop because of its long growing season and late maturation but is affected by weather in much the same manner as spring grains.

14. See Appendix B for sources and methodology of these models.

15. Technology includes application of fertilizer, herbicides, and insecticides; improvements in seed varieties; use of machinery; and application of agronomically sound principles of crop rotation, fallow, and soil management.

16. To some extent these local constants did affect the technology trends, since technological advances are not evenly applied to the entire country and each region showed different technology trends.

84% of the variance of winter wheat yields and 73% of the variance of spring wheat yields. The remaining variance is assumed to be due to random errors in the data and short duration weather events not reflected in the monthly averages. Neither of these alter the weather trends.

26. Variations in the weather caused production to fluctuate sharply from year to year, ranging from a low of 107.5 million tons in 1963 to a high of 222.5 million tons in 1973. Nevertheless, between 1962 and 1974 total grain production in the Soviet grain belt increased at an average of 6.8 million tons per year (see Table 3).[17] This increase resulted from technological improvements and a climate change that generally favored grain production. According to the models, over half of this increase is directly attributable to improved climate.[18]

Table 3

USSR: Average Annual Change in All Grain Production, 1962-74

	Grain Area[1] (Million Hectares)	Average Increase in All Grain Production (Million Metric Tons/Year)	Caused by Climate Change (Million Metric Tons/Year)
Total	112.0	6.84	3.50
Baltics	2.2	0.28	0.05
Belorussia	2.8	0.42	0.01
Ukraine	16.7	1.62	0.94
Moldavia	0.9	0.11	0.03
RSFSR	71.3	3.49	1.71
Kazakhstan	18.1	0.92	0.76

1. Estimated grain area is based on the average harvested area during the most recent 5 years for which data are available. The 27 crop regions used in the models account for 112 million hectares of the 130 million hectares usually devoted to grain.

27. The impact of climate change was neither smooth nor steady during the period, nor did the impact occur equally in all regions. It is impossible to isolate

17. The Soviet Grain Belt refers to the 27 crop regions used in the computer model. These regions account for 86% of the sown area and more than 90% of the total production of all grains in the Soviet Union.

18. These estimates have been normalized to remove variations in total sown area and relative sown areas of various crops within crop regions. Changes in area are not as pronounced since 1962 as they were during the opening of the virgin lands in Kazakhstan in the 1950s, and their effect on the results of this experiment can be ignored. Difficulties in measuring the effect of weather (Appendix B) have already introduced some uncertainty in the relative effects of technology and weather, and the small adjustments for fluctuations in sown area would only make the task more complicated without improving the accuracy of the result.

the impact of climate change on grain production for individual years. By averaging data to remove annual weather variations, the impact of climate change over periods of several years can then be gauged. Most of the impact occurred during the late 1960s and the early 1970s (see Table 4). The early 1960s were marked by a pronounced biennial cycle in the drier regions with drought occurring on alternate years. As the intensity of the cycle waned in the late 1960s, the southward shift of the climate brought a stable period of increased moisture to the steppes and near-desert regions (see Table 5).

Table 4

USSR: Variations in Grain Production[1] Caused by Changing Climate

Million Metric Tons

	Base Period Production	Change Due to Climate		Total Change Due to Climate
	1962-65	1966-69	1970-73	1966-73
All Grain				
Total	440.9	103.0	137.7	240.7
Baltics	9.0	2.5	1.5	4.0
Belorussia	7.3	-0.8	0.1	-0.7
Ukraine	109.5	16.7	30.7	47.4
Moldavia	7.3	0.1	0.9	1.0
RSFSR	273.8	59.9	74.1	134.0
Kazakhstan	34.0	24.6	30.4	55.0
Winter Wheat				
Total	92.1	9.1	21.6	30.7
Baltics	1.1	-0.1	0.0	-0.1
Belorussia	1.3	-0.1	0.1	0.0
Ukraine	45.8	7.3	11.5	18.8
Moldavia	1.4	-0.3	0.0	-0.3
RSFSR	42.5	2.3	10.0	12.3
Spring Wheat				
Total	107.5	44.8	63.0	107.8
RSFSR	78.4	27.4	33.3	60.7
Kazakhstan	29.1	17.4	29.7	47.1

1. All production is based on yield data adjusted to 1962 technology and the average harvested area for the most recent five years for which data are available.

28. Winter and spring grains were affected differently by the change in climate, not only because of their different geographical locations, but also because

Table 5

USSR: Average Soil Moisture Weighted by Sown Area of Crop

Millimeters

	Winter Wheat			Spring Wheat			All Grain		
	1961-65	1966-70	1971-75	1961-65	1966-70	1971-75	1961-65	1966-70	1971-75
May	141	127	132	108	119	128	127	127	132
June	92	95	98	69	84	91	84	92	97
July	60	62	72	42	58	64	54	63	71
August	44	46	51	32	44	49	43	48	53

the timing of their growth stages requires different climate conditions for optimum growth. The regions that benefited most from the climate shift were the steppe regions of the RSFSR, the Ukraine, and Kazakhstan. The most dramatic effect was in Kazakhstan, where the increase in grain production was due almost totally to climate and where production doubled. This increase amounts to nearly one-fourth of the total increase due to climate for the entire USSR and it is in the most weather-vulnerable section of the grain belt. Changes due to climate in the wetter regions of the Soviet Union were negligible, becoming negative in the very wet regions such as Belorussia and the northern RSFSR, where excess moisture can be a problem for winter grain.

29. The impact of climate change since 1962 on yields of other grain is roughly comparable to that of wheat. Using the impact ratios for wheat and weighting by share of production suggest that approximately half of the increase in grain production since 1962 is attributable to climate changes.

30. A slight warming and dampening occurred during winters in the USSR's winter wheat regions. This was due to an influx of warmer, moister air from the North Atlantic. The models, however, indicate that since 1962 most of the improvement in winter wheat yields has been due to technology. From 1962 to 1974 winter wheat yields increased at an average annual rate of 0.90 centners per hectare, or about 5%.[19] It is estimated that 14% of the improvement in winter wheat yields since 1962 was the result of climate change.

31. In contrast with the winter wheat areas, there has been a much more beneficial climate change in the spring wheat area. In fact, most of the total trend

19. Centners per hectare is the most commonly used measure of grain yield in the Soviet Union. A centner is equal to 100 kilograms and a hectare is equal to 10,000 square meters.

of spring wheat yields can be explained by climate change. Yields estimated by the model without considering time trends show climate-related trends identical to the total trend of yields. The mean monthly precipitation from October through September shows a trend of the same magnitude as that of the spring wheat yields. Spring wheat yields rose by an average of 0.64 centners per hectare per year – 4% (see Figure 6). About 81% of the increase in spring wheat yields was due to the improved climate. Because most of the improved climate conditions occurred east of the Urals, spring wheat yields gained disproportionately.

32. A reduction of variability of summer precipitation in the spring wheat regions also has occurred since 1960. Historically, spring wheat yields, which vary with precipitation, have had a quasi-biennial cycle. This approximate two-year cycle of alternate wet and dry years exhibits periods of relative quiet (little or no variation) every 11 to 13 years.[20] Between 1962 and 1966 the spring wheat yields doubled and halved on alternate years, marking a period of high variability. From 1970 through 1973, year-to-year changes were on the order of 10%, marking this as a stable period. The downturn in 1974 followed by the sharp drop in 1975 may mark the start of another highly variable period.

Prospects

33. The Soviet Tenth Five-Year Plan (1976-80) set grain production targets at an average 215-220 million tons a year during the period, about one-fifth more than was realized on average during 1971-75. Attainment of this goal will depend, for the most part, on the climate. Theoretically, the future climate may remain constant, improve, or worsen in terms of impact on grain growing. In practice, while the climate cannot be forecasted, reasonable limits can be set that in turn may be used as the basis to project grain production. Moreover, some climate trends

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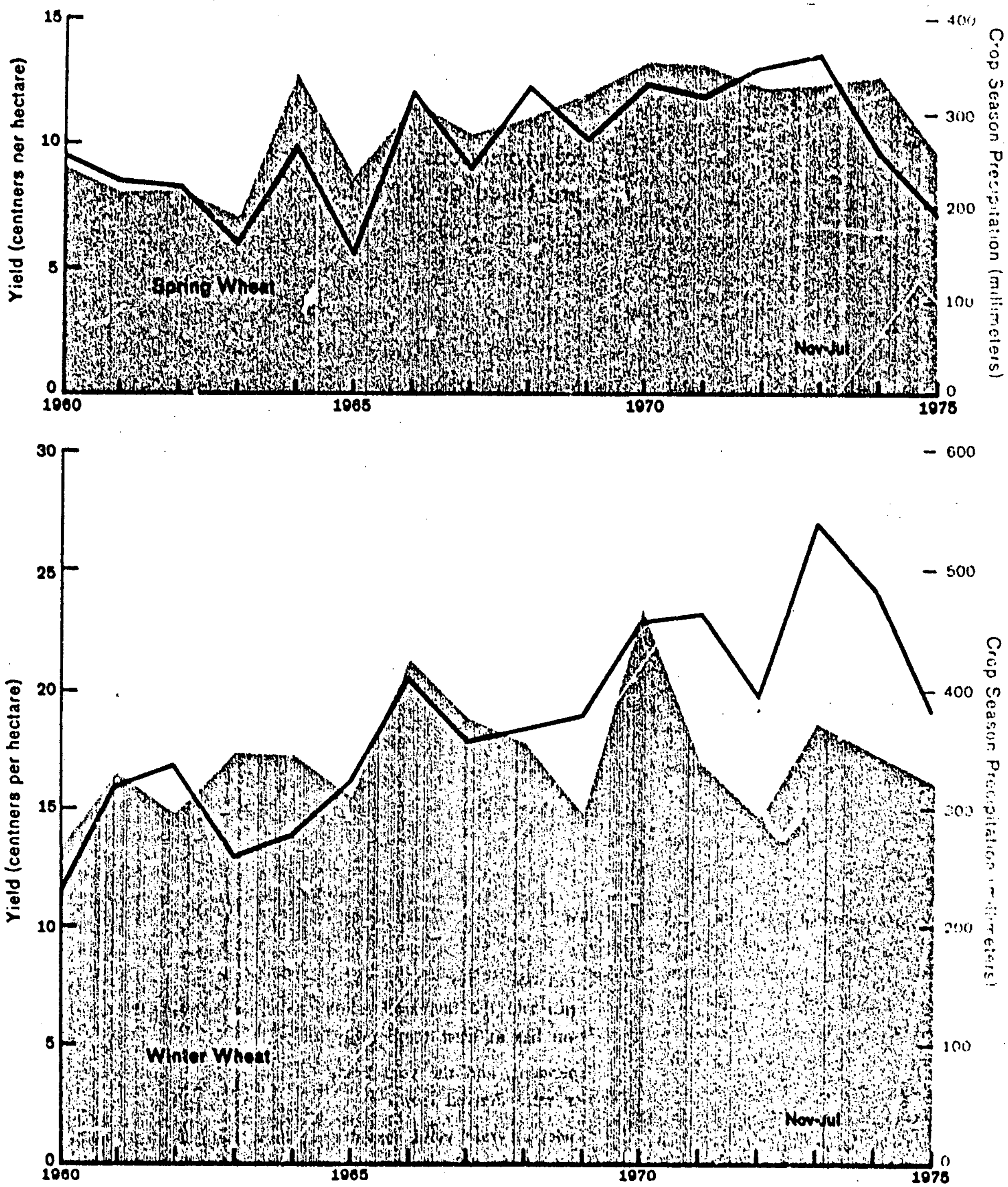
20. The existence of a quasi-biennial cycle in the Soviet Union has been discussed by many Soviet meteorologists, climatologists, and agronomists. For example, P.I. Koloskov, in his book ***The Climatic Factor in Agriculture and Agroclimatic Zoning***, Moscow, 1971, discusses the possible use of this feature as a forecasting tool for seasonal weather. This cycle is very persistant, but it is not a true biennial cycle. It is very pronounced for a period of years; then it may not be evident for several years. In the grain region of the Soviet Union this cycle of large and small biennial fluctuations requires about 12 years to complete. This does not, however, mean that weather repeats itself every 12 years, but rather that the wide fluctuations of the 1960s and the stable weather of the early 1970s is a normal occurance. What is unusual is the high precipitation level at which this stable period occurred.

Koloskov offers a possible explanation for the quasi-biennial cycle, which may or may not be accurate. Simply stated, warm winters are followed, most probably, by warm springs. This causes a wind flow that brings rainfall and clouds that in turn produce a cool summer. The cool summer sets up conditions that lead to a cold winter, which gives the reverse weather the following summer. A hot, dry summer then leads to warm winter and the cycle begins over again.

Figure 6

USSR: Wheat Yields and Crop Season Total Precipitation



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seem more likely than others. For example, the trend between 1960 and 1974 toward greater precipitation is unlikely to continue because of the physical limitations of the atmosphere to transport water from the North Atlantic to the Soviet grain belt. The recent wet period in the Soviet grain belt was unusually wet when compared to the past and the worldwide climate conditions in the Northern Hemisphere that accompanied it seem to have abated.[21] It therefore seems more likely that the future course of the climate in the Soviet grain belt will be toward less precipitation, either gradually or rapidly.

34. Below we set forth three projections of yields for spring wheat and winter wheat. Two of the projections are based on differing average climatic conditions for the Soviet grain belt over four-year periods since 1960 – the average "worst years" and average "best years." The remaining projection is based on the average conditions during 1962-75. The projections cannot be used to predict actual grain production during 1976-80, but they do indicate the likely limits to which production will occur. Moreover, the projections are a useful analytieal tool in assessing the USSR's likelihood of attaining the Tenth Five-Year Plan grain goal.

35. Even the limits set by the "best" and "worst" projections must be viewed with caution. First, they represent four-year averages, and Soviet grain production is noteworthy for its sharp year-to-year deviations from the trend. For example, grain production in 1975 illustrated the extremes to which year-to-year fluctuations occur; production was roughly two-thirds of the output in 1974.

36. Stated alternatively, when statistics are used to forecast the future, certain assumptions[22] are made that may not be true, having the effect of making the forecast meaningless. From a time trend of Soviet all grain yields from 1950 through 1974 it can be calculated[23] that there is only a 1 in 5,000 chance that the 1975

21. During this period (1970-73) the entire Northern Hemisphere was marked by a climatic fluctuation. The Sahelian drought and failures of the Indian monsoon appear to be linked to the increased rainfall in the Soviet Union. Though the causes of the fluctuation are unknown, its global extent is evident. Changes in hemispheric climate of this magnitude involve the movement of tremendous amounts of energy, which affect the temperature of land surfaces and oceans for several years and in turn influence future climate. The recent ending of the drought in Africa and the increased rainfall from the Indian monsoons support the hypothesis that this climate fluctuation has at least temporarily ended.

22. Data are usually assumed to be independent, and the year being forecasted for is assumed to be part of the same population that the statistics were derived from.

23. The projected value for 1975 of Soviet all grain yields based on a time trend from 1950-74 is 15.9 centners per hectare. The standard deviation of the differences between the time trend values and the actual values is 1.24 centners per hectare. Using 3.61 standard deviations from the mean as the .0001 limit for a one tail test gives a probability of .0002 for values outside the range 11.5-20.4 centners per hectare.

yield would be higher than 20.4 centners per hectare or lower than 11.5. The actual yield was 11.2, which is well outside the widest range statistics can set as possible. Moreover, if the 11-year cycle of fluctuation in the amplitude of the quasi-biennial cycle has ended, as seems likely, a period of greater variability in grain yields can be expected during 1976-80.

37. Finally, the method used in arriving at these projections uses two assumptions that tend to inflate the lower estimates. First, the effect of the time trend of technology is assumed to be independent of weather. The effect of weather on technology, particularly fertilizer application, tends to increase variability of production by increasing yields only when sufficient moisture is available. In dry years the application of mineral fertilizer may actually reduce production. The net result of this effect is that weather is nonlinear and therefore cannot be averaged before yields are computed. If weather during a period of fluctuating moisture supply is used to compute annual yields that are then averaged, the result is a lower mean yield than if the weather is first averaged and then used to compute a mean yield directly. The ratio of the variance to the mean of yields from 1962 through 1965 is twice that of yields from 1970 through 1973.

38. Second, the assumption that the "worst" weather possible occurred between 1962 and 1965 seems conservative. The worst four consecutive years of the early 1960s have a mean precipitation that is only 4% below the long-term average. The indication is that the early 1960s may be more representative of average future weather than it is a reasonable bottom limit.

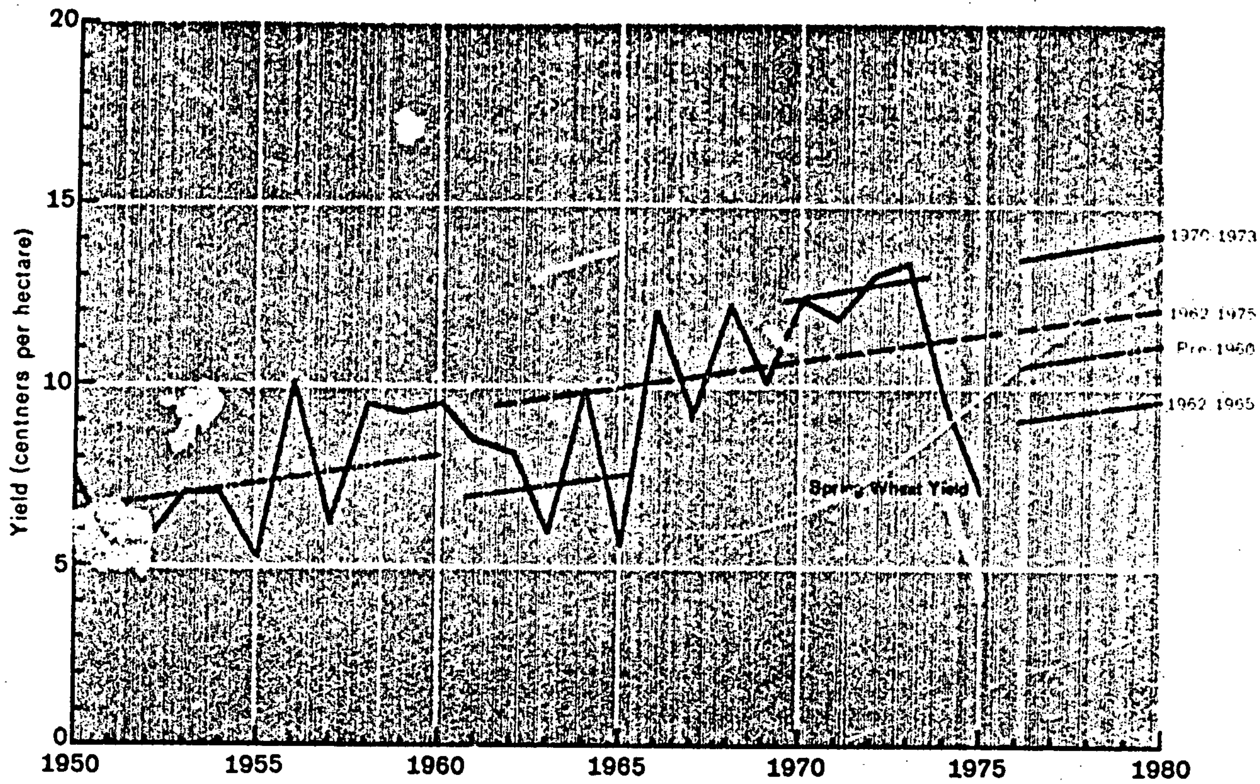
39. By combining past climate and an assumed constant technological development trend, future grain production can be estimated. The three projections were each based on mean weather parameters averaged over some past period (see Figures 7 and 8). These estimates of average weather were then used to compute yields of winter and spring wheat in each crop region, appropriate technological trend adjustments were made, and all grain productions were computed for each year from 1976-80 for each period's average weather.

Projection 1: The "Best" Case

This projection is based on the climate of 1970-73. Except for the winter grain crop of 1972, this was a period of stable, favorable weather in the grain belt. Precipitation was abundant and temperatures moderate. Winters in the winter grain region were warm (with the exception of 1972) and summers in the spring grain region were cool. If during 1976-80 these climate conditions prevail, winter and spring wheat yields will average 28.0 and 13.9 centners per hectare. Grain production would average 242 million tons per year through 1980 – more than one-third greater than average production during 1971-75. This projection seems highly unlikely.

Figure 7

USSR: Spring Wheat Yields and Projections Based on Weather from Various Years



The use of constant weather for each of the curves removes climatic effect. The resulting projections, therefore, are reflections of technological improvements only.

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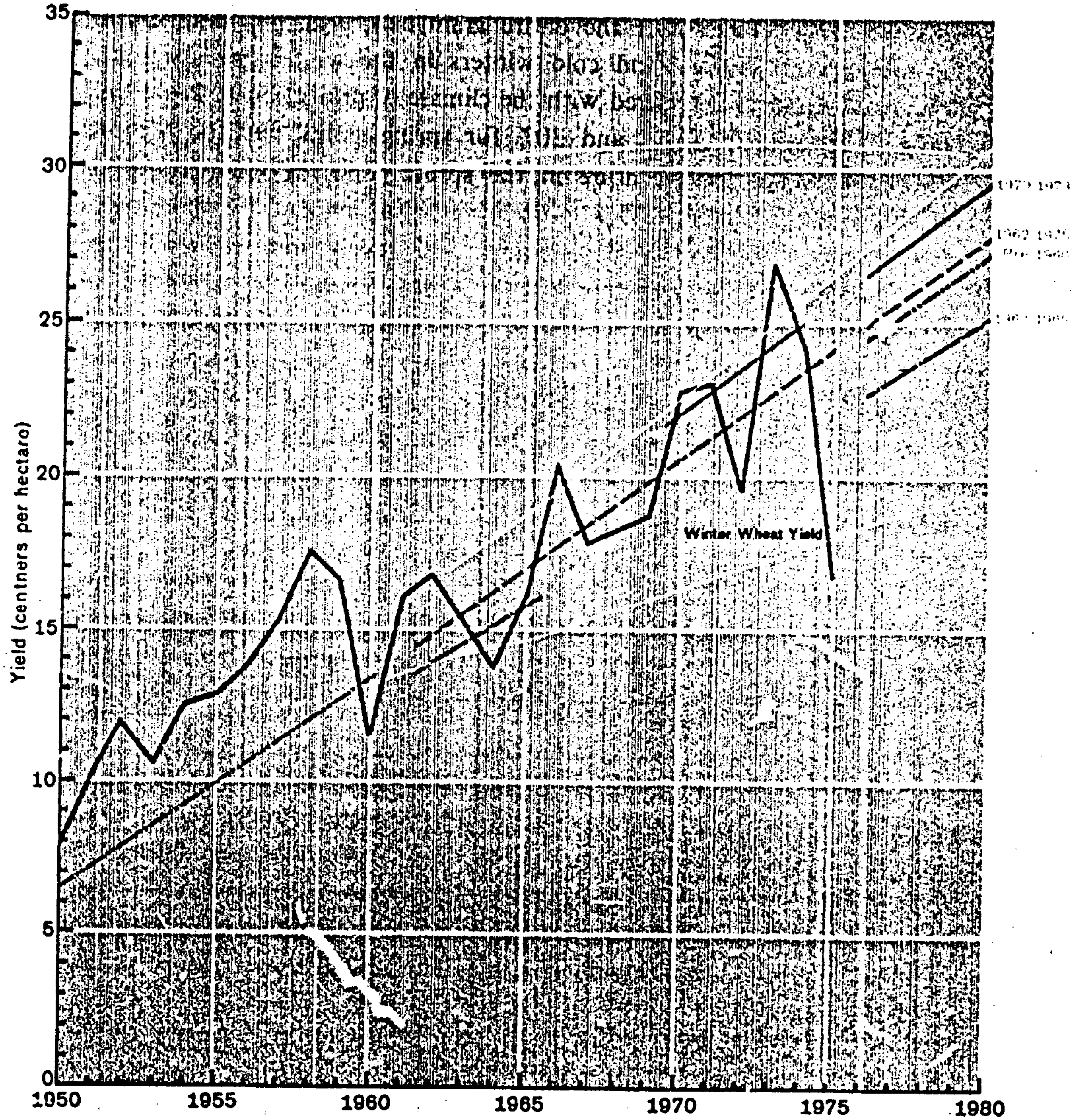
Projection 2: A Recent Average

This projection is based on the climate of 1962-75. This period encompasses a complete cycle of the variations in the spring grain quasi-biennial cycle from the maximum fluctuations of the early 1960s through the stable early 1970s. The high precipitation of the early 1970s more than made up for the dry early 1960s, making this period wetter than the long-term mean prior to 1960. This climate gives projected winter and spring wheat mean yields of 26.4 and 11.8 centners per hectare, respectively. All grain annual production would average 223 million tons per year under this assumption. Although this represents an 8% reduction from projection 1, it is still somewhat optimistic.

Figure 8

USSR: Winter Wheat Yields and Projections Based on Weather from Various Years



The use of constant weather for each of the curves removes climatic effect. The resulting projections, therefore, are reflections of technological improvements only.

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Projection 3: The "Worst" of the Recent Past

This projection is based on the climate of 1962-65. This period marks the worst four consecutive years of the past 15 years. The worst year was 1963, when production of both winter and spring grains suffered, and no year during the period was a good year for both types of grain. This was a dry period for the entire grain belt, with hot summers in the spring grain regions and cold winters in the winter grain regions. Precipitation, when compared with the climate of projection 1, was down 20% for the winter grains and 30% for spring grains, and the highest June through July temperature in the spring grain regions in the past 15 years was in 1965. This period was also marked by maximum amplitude of the quasi-biennial cycle in the spring grain regions. This climate gives projected winter and spring wheat mean yields of 24.0 and 9.3 centners per hectare, which, in turn, give an estimated all grain mean annual production of 200 million tons. This represents a 17% reduction of projection 1. By means of comparison, the Soviet goal of an average crop of about 217 million tons during the current five-year period seems merely to be an extension of the 1950-74 trend. If the disastrous harvest of 1975 is included in the trend since 1950, however, the average crop during 1976-80 is only 205 million tons. In any case, based only on trends in production, Soviet leaders can reasonably expect grain production during 1976-80 to exceed output in 1971-75. However, considering the climatic conditions necessary to achieve their goal, it appears unlikely that the goal will be met.

40. The estimated annual requirements for grain during 1976-80 is estimated at 225 million tons, based on projections of normal requirements for food, seed, industry, exports, and feed.[24] The projected level of production falls 25 million tons below the projected level of requirements. However, the level of probable imports does not necessarily equal the gap between production and requirements because, in the event of smaller crops, requirements likely would be reduced, as they were in 1975/76.

24. The methodologies underlying the estimate for the first four categories are explained in detail in CIA A (ER) 75-68, *The Soviet Grain Balance, 1960-73*, September 1975. The methodology for the feed estimate is based on official Soviet plans for livestock product output during the five-year period.

USSR: Köppen Climatic Classification by Crop Region for Crop Years 1962 to 1975

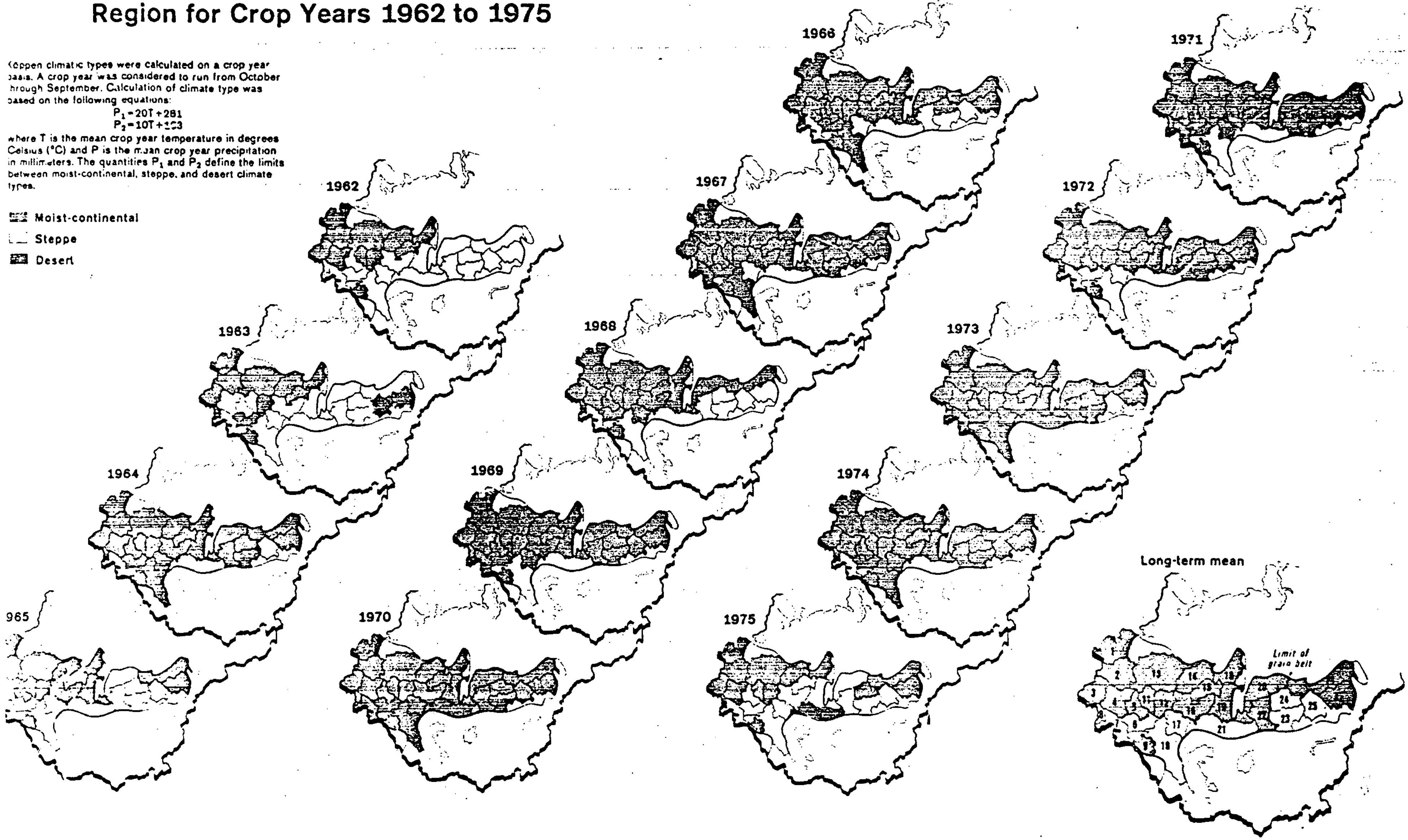
Köppen climatic types were calculated on a crop year basis. A crop year was considered to run from October through September. Calculation of climate type was based on the following equations:

$$P_1 = 20T + 281$$

$P_2 = 10T +$ 1[illegible]3

where T is the mean crop year temperature in degrees Celsius (°C) and P is the mean crop year precipitation in millimeters. The quantities P_1 and P_2 define the limits between moist-continental, steppe, and desert climate types.

- Moist-continental
- Steppe
- Desert



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APPENDIX B

METHODOLOGY FOR SEPARATING THE EFFECTS OF TECHNOLOGY AND CLIMATE ON SOVIET GRAIN YIELDS

Grain yields are a function of climate and technology. In the past it has been generally assumed that climate remains constant and that any upward trend in yields is due to technology, with annual weather difference causing the variance about this smooth trend line. However, a closer look at the data suggests that between 1962 and 1974 there was a significant improvement in the climate of the Soviet grain belt that makes this assumption invalid. The problem is therefore to separate the effects of technology from those of weather during this period. To do this a computer model was designed that would accurately describe past yields for spring wheat, winter wheat, and all grain for 27 crop regions, using monthly average weather data and estimates of technology derived from the residuals. These estimates of technology, when converted to fertilizer response rates, compare well with published Soviet data at the republic level of aggregation.

Formulation of the Model

Technology

During the past 15 years Soviet investment in agriculture has steadily increased. New varieties of their major grain types have been developed; fertilizer, lime, and insecticides have been used in greater quantity and in a more scientific manner, and new and better equipment has been made available to plant, care for, and harvest grain. These improvements are recognized as components of the technology trend, but insufficient data are available to estimate the quantitative effect of the improvement. Information on such improvements is incomplete and, when available, represents national or republic totals – not the individual crop regions required for the model.

Although the effect of technology on grain yields can not be directly measured, certain important assumptions can be made about the form of relationship that are believed to accurately reflect actual conditions.

The rate of change in application of technology, if present, will not change greatly from year to year for any one crop region. This allows the use of a linear trend for technology:

$$T = b + ct \qquad \text{(equation 1)}$$

where

T = technology

t = time in years

$c = \Delta T / \Delta t$

b = constant

The effect of technology (excluding irrigation) is weather dependent. For example, the application of one centner of fertilizer with 600 millimeters of annual precipitation will increase yield more than will the same centner of fertilizer with only 200 millimeters of annual precipitation. The effect of technology is, therefore, not additive. A first approximation of the effect is:

$$Y = TY^* \qquad \text{(equation 2)}$$

rather than

$$Y = T + Y^* \qquad \text{(equation 3)}$$

where

Y = yield

Y^* = yield based on weather conditions alone

Technology has not been evenly applied to the entire grain belt. There has been a tendency to apply technology first in those areas where the potential return was the greatest. The regions where climate is more favorable should have greater technology trends (greater values of c) than those with poorer climates. This was found to be the case.

Weather

Both technology and climate affect grain yields. The problem is to quantify the influence of each. Since there is a relative abundance of weather data, the use of regression analysis allows us to estimate the effect of weather on yields and thereby to treat the influence of technology as a residual. To determine the impact of weather on yields, the weather data for all years since 1962 for all regions in the Soviet grain belt were regressed against annual yields for these regions since 1962. This assumes that soil types and other differing physical characteristics between crop regions have no bearing on yields. While this oversimplification is not true, the importance of these differences on yields is minimal. To test this hypothesis, regions were grouped by annual mean precipitation, and the weather-yield coefficients did not change significantly, indicating – to a first approximation – the independence of yield to geographic location.

Data

The weather data used in the model include observations of precipitation and temperature for each of 27 crop regions from 1962 to the present. The observations are averaged and entered monthly into the data base for each crop region. In the early years of collection – roughly 1961-65 – data were transcribed by hand from weather maps, greatly limiting the number of stations that could be used. Since 1965 the data have been routinely processed by computer, thus enabling all reporting stations to be included. The change in the number of reporting stations was one of spacial density and not of shifting areas. The effect on monthly mean data should be negligible when aggregated to the crop region level.

The yield data cover all grain, spring wheat, and winter wheat for years 1962-74. Yields were calculated from published data for oblasts within a crop region, except for those few crop regions that coincide with the areas for which the USSR reports yields. Errors in the yield data can arise from inconsistencies in official Soviet statistics, the need to estimate unpublished data, and the ratio of sown area to aggregate yields. Although many inconsistencies appear in published Soviet sources, most involve a variance of only 0.1 centner per hectare. Wheat yields for the RSFSR are usually reported only for spring and winter wheat combined. By using additional information, yields for spring and winter wheat could be estimated separately. The estimates that could be checked were quite accurate; hence, any distortion is believed to be small.

The Model

Basic Equations

The model uses regression analysis of linear and quadratic weather parameters to develop a global qualitative equation relating yield to weather:

$$Y^*_{it} = a_0 + a_1(X_1)_{it} + a_2(X_2)_{it} + \ldots + a_n(x_n)_{it}$$

(equation 4)

where

Y^* = qualitative yield based only on weather data
a = regression coefficients
X = a value of temperature, precipitation, or calculated soil moisture averaged for any number of whole months (1-12) during the crop year. The crop year starts in October and extends through September of the year of harvest. The square of the value is also used when appropriate.
i = crop region
t = year

To compute the regression coefficients, all pairs of yield and weather data available for all 27 crop regions for 13 years are used simultaneously without regard to location or time.

To estimate the level and rate of change of technology in each of the 27 crop regions, the global equation (4 above) is solved for each year in each crop region, and a ratio of the qualitative weather yield to the reported yield is calculated. These ratios are the technology indexes:

$$T_{it} = Y_{it}/Y^*_{it}$$ (equation 5)

where

T = actual technology index
Y = reported yield
Y^* = weather based yield estimate
i = crop region
t = year (1962-75)

These technology indexes are then time trended to obtain a smooth function that removes random variance and allows values of T to be estimated for years for which no yield data are available and to project future values. Thus:

$$T^*_{it} = b_i + c_i t$$ (equation 6)

where

T^* = a calculated technology index
t = year

b_i and c_i are constants determined by linear regression of T with time (see equation 5)

To estimate the combined impact of weather and technology on yields, each value of Y^* is multiplied by the corresponding value of T^*. This allows yields to be computed for any crop region for any year in which the weather can by measured or estimated, including future years.

$$Y^{**} = T^* Y^* \qquad \text{(equation 7)}$$

where

Y^{**} = estimated yield and is a function of time and weather

$$Y^{**} = (b_i + c_i t)\,(a_0 + a_1 (X_1)_{it} + \ldots + a_n (X_n)_{it}) \qquad \text{(equation 8)}$$

where

b_i, c_i, and a_0 through a_n are constants

Parameters and Coefficients

An almost limitless number of combinations of weather parameters can be used in describing the changes in Soviet grain yields. For example, the weather data base contains only monthly values of temperature, precipitation, and soil moisture. These basic parameters can be averaged or summed over any combination of consecutive months, combined with each other using any algebraic form, changed to any functional form, or combinations of all of these. An extreme example might be:

$$X = (\overline{P}_{1-7})^2 - \exp\left[(\overline{T}_{1-7} + 273)/100\right]$$

where

X = new parameter

$\overline{P}_{1-7}$ = mean precipitation Oct-Apr

$\overline{T}_{1-7}$ = mean temperature Oct-Apr

Using a large number of parameters increases the model's ability to describe past yields but reduces the physiological correctness of the weather-yield relationships. Care must be taken that better description is not achieved for the wrong reasons. An example of this is the strong relationship between all grain yields and the average January-February temperature, which explains 58% of the variance of all grain yields from 1962-74. The reason for this correlation is that temperature is an indicator of the state of the climate. The usual climatic conditions that lead to a warm winter also produce above-average precipitation through the next summer. The winter of 1974-75 was one of the warmest on record, but was unusual because precipitation was far below normal. The entire year was dry, which reduced yields rather than increasing them as the winter temperature had indicated would happen. In any descriptive model all parameters must be evaluated for physiological correctness before using them. The major controlling factor for grain production in the Soviet Union is moisture. Available soil moisture when growth starts in the spring results from precipitation that fell from the late fall of the previous year until the start of growth. Once growth begins, temperature as well as precipitation becomes critical, particularly in the case of spring wheat. The model's parameters and their coefficients are given in Table B-1 and the model's estimated yields are compared with the officially reported yields (see Table B-2). No officially reported yield data are available for 1975 at the crop region level.

Table B-1

USSR: Weather Parameters and Coefficients for the Global Equation

All grain	Coefficient	Standard Error
a0	-2.23	
a1 precipitation Nov-Apr[1]	0.171	0.0277
a2 precipitation May-Jun	0.260	0.176
a3 above squared	-0.000592	0.0000129
Winter wheat		
a0	0.860	
a1 precipitation Nov-Apr	0.121	0.0284
a2 precipitation May-Jun	0.311	0.226
a3 above squared	-0.00111	0.0000145
Spring wheat		
a0	0.683	
a1 temperature Jun	0.317	1.58
a2 temperature Jul	0.367	1.27
a3 precipitation May-Jun.	0.119	0.0461
a4 soil moisture Jun-Jul[2]	0.156	0.0777
a5 above squared	0.000736	0.00000174

1. Mean monthly precipitation over the months indicated.
2. Soil moisture is calculated from temperature and precipitation daily data and reported monthly. Values range from 0 to 200 millimeters.

Measuring Technology

Substitution of weather data into the global equation explains between 40% and 50% of the variance of the yields (equation 4). Adding the means (equation 6) and linear time trends for each crop region for technology indexes increases the

Table B-2

USSR: Comparison of Reported Yields and Yields Computed by the Model

Centners per Hectare

	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
All grain														
Reported	10.9	8.3	11.4	9.5	13.7	12.1	14.0	13.2	15.6	15.4	14.0	17.6	15.4	10.9
Computed	10.3	8.7	13.4	10.7	15.0	13.2	12.6	14.3	18.6	16.2	14.1	17.4	19.0	12.9
Winter wheat														
Reported	16.8	12.9	13.8	16.1	20.4	17.8	18.3	18.9	22.8	23.1	19.6	26.9	24.0	18.7
Computed	14.2	15.0	17.6	16.8	21.7	20.7	18.4	21.0	26.7	22.9	20.4	27.2	27.5	22.7
Spring wheat														
Reported	8.2	5.9	9.9	5.5	12.0	8.9	12.2	10.1	12.3	11.8	13.0	13.4	9.5	7.0
Computed	7.5	5.5	11.9	7.3	10.6	9.6	9.9	11.9	13.2	12.6	12.3	13.7	13.6	8.4

explained variance to 70% to 80%, depending on the crop. The remaining variance is due to random noise in the data caused in part by a lack of resolution.

To separate the effects of technology and weather, the yields since 1962 for each crop region for each year were adjusted to 1962 technology (see Table B-3).

Table B-3

USSR: Comparison of Reported All Grain Yields and Yields Adjusted to 1962 Technology

Centners per Hectare

	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Baltics													
Reported	8.6	9.4	12.1	16.7	14.1	17.8	19.4	22.8	22.9	26.2	18.3	19.0	27.1
1962 technology	8.6	8.7	10.3	13.3	10.5	12.4	12.8	14.2	13.5	14.7	9.8	9.7	13.3
Belorussia													
Reported	6.9	8.0	7.2	11.5	10.5	11.3	11.0	15.9	16.9	21.4	17.3	21.2	26.2
1962 technology	6.9	6.7	5.1	7.2	5.8	5.6	5.0	6.6	6.5	7.6	5.7	6.6	7.6
Ukraine													
Reported	17.9	12.9	17.6	19.2	21.5	20.5	18.5	23.0	23.4	25.5	21.2	29.0	27.6
1962 technology	17.9	12.6	17.0	18.1	20.0	18.7	16.6	20.4	20.3	21.8	17.7	24.2	22.8
Moldavia													
Reported	23.6	17.0	19.7	25.8	26.3	22.6	23.2	27.5	29.3	26.9	34.3	33.6	33.1
1962 technology	23.6	16.4	18.4	23.3	23.0	19.1	19.0	21.9	22.7	20.3	25.1	24.0	23.0
RSFSR													
Reported	11.4	8.4	10.9	9.1	13.2	11.9	15.0	12.6	16.1	14.7	12.6	15.1	17.2
1962 technology	11.4	8.2	10.5	8.4	12.2	10.7	13.2	10.6	13.8	12.3	10.5	12.3	14.2
Kazakhstan													
Reported	4.5	4.1	7.8	2.9	10.8	6.1	8.6	9.5	9.5	9.3	12.2	9.5	9.7
1962 technology	4.5	4.0	7.5	2.8	10.2	5.8	7.9	8.5	8.7	8.5	11.3	8.6	8.7

By doing this, variations in yield are caused solely by weather. The adjusted yields were computed using the following equation*:

$$Y'_{it} = (b_i + 1962c_i)Y_i / (b_i + c_it) \qquad \text{(equation 9)}$$

where

Y' = yield assuming 1962 technology
Y = reported yield
b, c = intercept and slope from equation 6
t = year
i = crop region

It is not possible to explain all the weather effect using the data base available, and therefore it is not possible to prove from the weather and yield data alone that this is in fact a quantitative measure of technology. However, Soviet reports of fertilizer applications (the main technological development) by republic are consistent with the model's measurements.

Fertilizer response rates are computed from the current nutrient application rate and the yearly changes in yield, assuming that application rates were zero in 1962 (see Table B-4). Using the calculated technology trends results in response rates that are very close to the rate reported by Soviet agronomists.**

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* In formulating the model, yield was assumed to be due to the combined effects of weather and technology. An estimate of the weather effect, in the form of a yield from the global equation, was multiplied by the appropriate technology index to get the estimated yield. To adjust any reported yield to the technology of 1962, the process is reversed. The reported yield is divided by the appropriate year's technology index to get the assumed weather effect, which is then multiplied by the 1962 technology index to get a yield using 1962 technology.

$$Y^*_{it} = Y_{it}/T_{it} \qquad \text{from equation 5}$$

$$Y_{i(62)} = Y^*_{it}T_{i(62)} = \frac{T_{i(62)}}{T_{it}} Y_{it}$$

$$T_{it} = b_i + c_it \qquad \text{from equation 6}$$

therefore

$$Y_{i(62)} = \frac{b_i + c_i \times 1962.0}{b_i + c_it} Y_{it}$$

** Using the total time trend as a surrogate for technology gives response rates that vary in contrast, from 1.8 in Belorussia to 13.5 in Kazakhstan.

Table B-4

USSR: Trend in Yields, Fertilizer Application Rates, and Response Rates

Region	Average Annual Increase in All Grain Yield, 1962-74 (Centners per Hectare): Due to Weather and Technology	Due to Weather Alone	Due to Technology Alone	Application of 100% Nutrients in 1974 (Centners per Hectare)	Response Rate[1] (Unit Increase of Yield per Unit Increase of Fertilizer)
Baltics	1.29	0.24	1.05	1.69	1.64
Belorussia	1.50	0.05	1.45	2.17	1.76
Ukraine	0.97	0.56	0.41	0.78	1.38
Moldavia	1.17	0.30	0.87	0.98	2.35
RSFSR	0.49[2]	0.24	0.25	0.36	1.83
Kazakhstan	0.51[2]	0.42	0.09	0.10	2.37

1. Response rates are computed assuming (1) that 22% of the gross weight of applied fertilizer is nutrient and (2) that no fertilizer was applied as of 1962 and a linear increase occurred each year through 1974. Soviet data indicate that (1) virtually no fertilizer was applied in 1962 and, (2) although increases in applications have been greater in recent years than in earlier years (a nonlinear increase), a linear approximation is quite close to the actual application rates over this period.

$$RR = rt\overline{\Delta Y}/N$$

where
RR = response rate
$\overline{\Delta Y}$ = average annual change in yield (centners per hectare per year)
N = 1974 nutrient application rate (centners per hectare)
t = 1974 minus 1962 = 12 years
r = ratio of nutrients to gross weight of fertilizer = 0.22

2. Average annual change, 1962-73.