



Dessicated Steppes. Drought and climate change in the USSR, 1960s-1980s

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<CN>Chapter 5

<CT>Desiccated Steppes

<CST>Droughts and Climate Change in the USSR, 1960s–1980s

<CA>Marc Elie

<TX>After settlers had plowed up vast areas of land in western Siberia, the Altai and Ural regions, and northern Kazakhstan in the course of the Virgin Land Campaign (1954–1960), the weather soon appeared to disrupt the efforts of these “New-Landers,” (*tselinniki*) as they were known. The first half of the 1960s saw devastating droughts, dry winds (*sukhovei*), and destructive sand storms, similar to the North American Dust Bowl of the 1930s.ⁱ From the end of the 1960s through the 1980s, droughts plagued the steppes of Ukraine, Russia, and northern Kazakhstan, regions that were the main grain suppliers of the Soviet Union.ⁱⁱ One visible consequence of periodic crop failures was that the Soviet government was forced to import grain beginning in 1963, using gold reserves, and later, petrodollars.ⁱⁱⁱ Agricultural production, notwithstanding significant investment in chemicals, mechanization, and subventions, stagnated in the 1970s and 1980s.

In the 1970s scientists and politicians sensed that something was going wrong in the steppes. For many Soviet observers, the weather had turned mad, the natural conditions for farming were degrading, and steppe agriculture seemed deadlocked in a struggle against a changing environment. Research on the steppe environment then focused on droughts and correlated phenomena because they were the most blatant symptoms of the perceived changes. Temperatures were rising, soils were getting drier, water levels were declining in rivers, and dry winds were blowing away the soils. At the same time, many saw crop failures during droughts as

the result of improper farming practices, leading to soil impoverishment and erosion. Russian and Soviet earth scientists considered both climatic change and agricultural policies as key to understanding the trouble with dry farming on the steppes.

In this article I focus on how conceptions of drought evolved among Soviet scientists from the eve of the Virgin Lands Campaign (VLC) at the end of Joseph Stalin's reign to the final years of the Soviet empire in the 1980s. I do not provide a complete review of the approaches taken by different scientific disciplines on drought. Instead, I concentrate on three disputed issues: the respective weight of human and natural factors, knowledge about drought before and during the VLC, and explanations for the drought crisis of the 1970s through 1980s. I handle the first issue not only as a discussion of whether Soviet meteorologists envisaged drought as a natural or an anthropogenic phenomenon but also as a general discussion of how approaching Soviet agriculture with the tools of environmental history can enhance our understanding of intertwined natural and social processes. Then I explain how Soviet scientists made major achievements in drought conceptualization and assessment in the first half of the twentieth century but were nonetheless helpless when the post-Stalin leadership launched the VLC because the climate of the regions where it played out had been understudied. Finally, I explore how political leaders, agronomists, and climatologists accounted for the perceived "aridization" of the steppes in the 1970s and 1980s.

<Insert Map 5.1 about here>

<H1>Toward an Environmental History of Soviet Agriculture

<TX>The impact of the weather on Russian and Soviet crop yields has been a subject of considerable study both in the USSR and abroad. Meteorologists, agronomists, geographers, economists, and historians have tried to assess the conditions that produced the long list of crop

failures, crippling Soviet farms and bringing deadly famines (1921–1922, 1932–1933, and 1946–1947) and countless food crises. How responsible is moisture deficiency for Soviet agriculture’s haphazard and overall poor performance, in contrast to governmental policy and technological advancement in a command economy? Collectivization removing all autonomy in farming decision from farm managers and peasants, artificially low state procurement prices, misguided melioration campaigns and many other socio-economic factors hindered the performance of Soviet farms.^{iv} By contrast,

in their 2005 book, Nikolai Dronin and Edward G. Bellinger argue that weather conditions were the strongest factor influencing yields in the Soviet period. Irregular precipitation accounts for most of their considerable yearly oscillations. “In most cases, statistical data on harvests in Russia are in compliance with weather characteristics,” they observe. Bad harvests occur when the year is dry, and the harvest is good in moist years.^v In their view, the famines of 1921–1922, 1931–1933, and 1946–1947 were caused by violent procurement campaigns and so were exceptional, pure products of Bolshevism and Stalin’s dictatorship.^{vi} But apart from these events, Dronin and Bellinger tend to emphasize climatic factors and downplay the impact of politics and economics. They hold the political leadership responsible for food crises when it set the wrong incentives via the price policy. But they ignore the question of how political decisions relative to the farm economy prepared farms for the drought or, on the contrary, weakened them; worsened drought manifestations or, on the contrary, alleviated them. They treat droughts as purely physical meteorological events, not as products of nature-society interactions.

I plead for another understanding of drought in the Soviet Union. In place of trying to parse human-made and climatic factors to explain diminishing yields, I propose to analyze these

factors as interacting together, feeding one another, in one drought process. This approach leans on several observations. First, scholars have already debunked the preconception that catastrophes are natural phenomena that strike society from the outside. They criticize the expression “natural disasters,” because it implies that disasters are physical events, insisting they are instead socially and historically constructed.^{vii} They refuse to link “nature” and “society” with a one-way relationship wherein physical events strike social processes; they show that they are deeply intertwined. Furthermore, neither nature nor society is a closed entity, “vulnerability” is a key concept to approach how different groups within a society—or countries within an international system—are more or less exposed to natural hazards and risks, with the poor and the weak usually more subject to disasters than the wealthy and secure.^{viii} Analyzing disasters requires examining the fabric of society to comprehend how its members are situated on the sociogeographical scale and how marginalization increases exposure to hazards.^{ix} Remarkably, the Sahel drought of the 1960s–1970s provided the first case whereby scholars redefined disaster studies, shifting the focus from technical expertise to social problems and provoking a “vulnerability turn” in the discipline.^x

In a famous book on the Sahel famine, atmospheric physicist Rolando García deplores the “tendency to consider both climate itself and the climatic fluctuations as a given.” To him, “climatic phenomena are only meaningful with reference to a certain society.” He proposes therefore to distinguish between “water deficiency” and “drought,” the former being the result of a hydrological and meteorological assessment, whereas the latter is “defined with reference to a certain productive system” whose expectations of the weather (expectations upon which crops, chemicals, machinery, and timing are chosen) are deceived by a stronger-than-normal climatic variability. A lack of water is not sufficient to explain a drought disaster. The vulnerability of an

agricultural system to climatic variability is the result of economic and political processes. Plants need more or less water depending on the chosen species and variety, different soils have different water capacities and drought resilience, water may be or not be used for irrigation, and so on. Depending on its configuration, a farm is more or less vulnerable to drought. García proposes therefore a definition of drought as “the social perception of a water deficiency with reference to a normal condition socially defined.”^{xi}

This provocative formulation of drought as perception should serve as a reminder that drought is never only a product of atmospheric physics and hydrology. García’s definition reminds us that disastrous droughts are not sufficiently explained by a lack of water. This is why conventional definitions of drought usually refer to agricultural requirements. Consider the definition proposed by the US National Drought Mitigation Center at the University of Nebraska–Lincoln: “Drought is a protracted period of deficient precipitation resulting in extensive damage to *crops*, resulting in loss of *yield*” (my emphasis).^{xii} Climatologists themselves do not nowadays frame drought as a physical event only; they recognize that social vulnerability plays a key role.^{xiii}

A second consideration for understanding drought as a process within the agricultural system comes from environmental studies. In agriculture, as in any other productive activity, natural processes are shaped by human intervention and harnessed to societal needs. Agriculture is the effort to bend biological, pedological, meteorological, and hydrological forces to the needs of human consumption. Natural processes in soils, the atmosphere, and waters cannot be considered external to production; they are integrated with human labor in one system.^{xiv} Industrial farming in the nineteenth and twentieth centuries changed the traditional balance of natural and anthropic processes through a considerable increase in mechanical, chemical,

financial, and scientific inputs such as selected seeds, heavy machinery, and plant-protecting and soil-enriching chemicals.^{xv} Furthermore, states have greatly expanded cultivated areas to the detriment of forests and grasslands, triggering far-reaching changes in ecosystems and in the biosphere. The human impact on them has considerably increased since the beginning of the Anthropocene.^{xvi} The Soviet Union showed extreme voluntarism and transformism, aiming to control the immensity and adversity of the Eurasian territory and to overcome the limitations and plagues of traditional Russian agriculture.^{xvii} A striking case of artificialization of natural elements is the modification of watercourses for irrigation in the North Caucasus and Central Asia, as Christian Teichmann and Julia Obertreis explore later (this volume).^{xviii}

But is not the weather different from other natural forces and entities like soils and waters? Farmers can't bend the weather toward their needs as they do soils, fauna, flora, and water. Likewise, they can't mismanage and devastate it. However, with a growing understanding of how human activities affected the climate in the nineteenth and twentieth centuries, it is no longer considered independent of human agency. Climate has ceased to be considered the ultimate exogenous factor for societal change.^{xix} As a whole, agriculture is a major contributor to climate change via deforestation, cultivation, and emission of greenhouse gases. But it still holds that climate is not directly manipulable by farmers (as animals, plants, soils and water are). Therefore, there is no direct link between the production of food in farms and droughts hitting rural economies, contrary to the situations when maladapted agricultural practices, overuse of chemical fertilizer, and reduced biodiversity can backfire on farmers in the form of erosion, pollution, and diminishing yields. This said, and remembering García's warning, drought is not a natural fact imposed upon the productive system. Donald Worster has shown how quickly changing economic patterns produced the North American Dust Bowl in the 1930s: capitalistic

farming replaced pasture lands with mechanized wheat monoculture on the Great Plains in the 1910s and 1920s, exposing farmers both to the negative impact of a decade of low rainfall and to the Great Depression of the 1930s.^{xx} Moreover, farmers must gamble on the stability of the weather. They were lulled into believing that the good wet years they had known until 1930 were a stable feature of the Great Plains climate, not a temporary opportunity that would sooner or later give way to series of dry years. The low rainfall of the 1930s defied the weather expectations on which they had built their farm economy. The same was true of New Landers on the Eurasian steppes: a wet year allowed for a bumper harvest in 1956, when the VLC had reached cruising speed, making many—foremost Nikita Khrushchev—believe that the rapacious plow-up had been the right thing to do.^{xxi}

We see the entanglement of natural and social processes at work in agriculture generally and drought particularly when farmers augment their control of natural processes and spaces. Roughly speaking, drought is the downside of the agricultural extension of Russia and the Soviet Union into the dry steppe in the nineteenth and twentieth centuries. But we shouldn't overemphasize control. Natural processes have their own force and follow their own dynamics, which have not been entirely controlled and predictable, notwithstanding the claim to do so in the age of "high modernism."^{xxii} For this reason, more often than not, well-meant agro-technical decisions brought adverse, unanticipated side effects to Soviet farms: after years of lobbying the government and only after Khrushchev's fall did Kazakhstani agronomists succeed in imposing a fallow-wheat crop rotation on the Virgin Lands, to leave soils time to recover and accumulate moisture and nutrients. Although created to conserve the soils (it was named "soil-preserving"), this system worsened erosion in the long run, because unprotected fields are more prone to deflation than cropped fields.^{xxiii}

A third motive for considering drought as a social phenomenon stems from the work of Soviet natural scientists. They hinted at the entanglement of natural and societal forces in drought formation when they discussed whether a purely physical definition of drought was possible and desirable. Meteorologists Vladimir Loginov and Anatolii Uteshev called for a universal definition of drought based on the discovery of meteorological laws. They criticized scholars who inferred meteorological conditions from yield data. Especially during earlier periods without instrumental measurements of weather (but for the Soviet period, too), many meteorologists used yield data as a proxy for weather situations. Roughly speaking, a bad harvest meant that the year was dominated by drought (as seen above, yields and weather show a strong correlation). Or they would compare yield curves (a proxy for biological production) to meteorological ones and use yields to confirm or contradict the characterization of a given year as drought-stricken and assess its severity. For Loginov, such an “agronomic” definition of drought “can’t be objective” because yields do not depend exclusively on weather.^{xxiv} Uteshev added that working with a purely meteorological definition of drought would help understand its effect on other plants and animals, whereas the use of harvest data, almost exclusively for wheat, nailed the analysis to one crop.^{xxv}

Against Loginov and Uteshev, Feofan Davitaia and Oleg Drozdov criticized the quest for a purely physical definition of drought as naïve and fruitless. For agrometeorologist Davitaia, droughts are “agro-hydro-meteorological phenomena” that cannot be studied “outside of the object which they impact and without accounting for the agricultural techniques used” on the farms.^{xxvi} The classical definition of drought given by the agronomist Vladimir Rotmistrov in 1913 stresses the link between weather, water, soil, and plant in drought: “Drought is a rainless period of a length such as to exhaust moisture accessible to plants in the root layer of the

soil.”^{xxvii} Drought is not the mere lack of rainfall, but a deficiency of moisture. To this we should add: not for all plants, but for crops; not all year long, but during the vegetative period; and so on. An objective meteorological definition of drought is possible, argues Drozdov, but climate data says nothing until the anomaly series are compared with that of plant development and other processes.^{xxviii} The interesting question is: What weather conditions are detrimental to water availability, to soil moisture, and to plant and animal development in a given region’s particular agricultural system? Or, to reverse the question: What selection of crops and soils makes a farm vulnerable to which departures of the weather from the long-term norm?

Most Soviet meteorologists agreed that there can be no universal characterization of drought. For Davitaia, “criteria for drought ... cannot be universal. What is drought for a type of plant raised using some agricultural practices can be optimal conditions for another type with more advanced agricultural practices.”^{xxix} Drozdov adds that a given drought level in the Moscow region can represent perfectly fit moisture conditions in central Kazakhstan. The same is true of soil drought: soils are differently affected by a lack of moisture. In Karelia in the north of Russia, pedological drought occurs even after a short interruption in spring rainfall because soils are shallow and rest on a rocky foundation. The same is true of peat bogs that have bad capillary properties, so that plants suffer from water deficit with even a small negative variation from the norm. Therefore, Drozdov observes, drought disappears as a clear-cut natural phenomenon.^{xxx} Drought characterization is more deeply dependent on human agricultural parameters than are lightning, avalanches, or forest fires. Floods are other such phenomena that are heavily dependent, in their definition and their development, on societal factors and parameters.^{xxxi}

The regional character of drought definitions is reflected in the difficulty of transferring the operational definition of drought (often crystallized in indices) from the region for which they have been created to other regions. The famous Palmer Drought Severity Index works best for arid and semi-arid regions in the United States. As in many other arid regions of the world, it was not adopted in Russia.^{xxxii}

Practicing an environmental history of agriculture does not mean introducing “nature” into the narrative. Economic historians do not ignore nature in their studies of Soviet agriculture. They handle physical phenomena such as weather and climate, more rarely waters and soils. But, adopting the methodologies of agrometeorologists, they isolate and ponder the weather, the economy, and politics as factors to explain the outcomes of Soviet agriculture. One of their key imperatives is to find methods to distinguish natural from other factors in harvest data. In their view these natural factors obtrude on agriculture.^{xxxiii} In contrast, environmental historians do not assign weight to each factor, for instance by insisting that natural factors are more determinant than social or economic ones. They analyze these factors as entangled in feedback processes and refrain from speaking of an exogenous, direct, and one-way impact of physical processes on society, because nature in agriculture is mediated by the production process.^{xxxiv}

<H1>Climate knowledge and the Virgin Land Campaign

<TX>After having discussed how environmental history can enhance our understanding of drought and agriculture, let’s move to the body of knowledge on steppe climate accumulated by Soviet scientists on the eve of the VLC. The motivation for this review comes from the bewilderment of the historians when they observe that the New Landers had no usable knowledge of droughts when they rolled into the eastern steppes, although Soviet science had

made major achievements in climatology, agrometeorology, and drought study in the first half of the twentieth century. To account for this paradox is the goal of this section.

When Stalin's heirs launched the VLC in 1954, politicians and scientists had long recognized that drought was the major calamity of Russian and Soviet agriculture. The famine of 1891 had triggered state reaction on an unprecedented scale in Russia and had led many scientists to look for solutions: the father of modern pedology, Vasilii Dokuchaev (1846–1903), went on an expedition to the drought region. His widely read book *Our Steppes: Past and Present* (1892) analyzed the causes of the crop failure and set up a plan to render Russian agriculture resilient to drought.^{xxxv}

In the first decades of the twentieth century, Russian climatologists and agronomists made several breakthroughs in measuring drought intensity and explaining their causes. Aleksandr Voeikov (1842–1915) and Petr Brounov (1853–1927) founded agrometeorology, a discipline crossing plant physiology, pedology, and weather data with harvest statistics. Drought theory and prevention is a major field of study for agrometeorologists.^{xxxvi} On the eve of the First World War, Brounov, chief of the Meteorological Bureau of the Ministry of Agriculture, designed the first drought probability maps. In 1915 Boris Mul'tanovskii (1876–1938) of the Main Physical Observatory in Petrograd gave a comprehensive explanation of atmospheric drought formation over European Russia and Ukraine. Linking drought to a peculiar type of atmospheric circulation, he showed that air descending from the North Pole southward along the Volga meridian dries out along the way and forms anticyclones over eastern Europe and southern Russia. Later meteorologists corroborated and refined his theory, showing that severe droughts occur when highs remain stationary for several weeks, “blocking” moist westerlies.^{xxxvii}

During the Civil War, in April 1921, the young Bolshevik state created an agrometeorological service for the whole Russian Republic, the first of its kind in the world. In early Soviet times, drought research progressed unabated, with the terrible 1921 famine triggering more meteorological investigations. The network of agrometeorological stations, already large before the war, increased tenfold in the 1920s.^{xxxviii} To measure drought magnitude, Georgii Selianinov (1887–1966) proposed a simple index in 1928, the hydrothermal coefficient (HTC; *gidrotermicheskii koeffitsient*), which is still widely used today to map drought in former Soviet countries.^{xxxix} The HTC represents precipitation deficit as the relationship of precipitation to evaporation. It is defined as the quotient of precipitation in millimeters (multiplied by a coefficient of 10) to the sum of temperatures above 10°C for some period of time, usually the three main growth months in the steppe region (June, July, and August).^{xl} The weaknesses of this index are that it does not account for soil moisture prior to the beginning of the vegetation and that temperatures is a very rough approximation of evaporation.

The industrializing Stalinist state lent support to meteorologists in the form of an expanding network of meteorological stations covering all time zone and geographical regions. Motivation for this investment was agronomic, but weather forecasting is essential also for war strategy and planning and for flying airplanes and guiding missiles, key tasks during the Second World War and the Cold War. As a result, drought specialists benefited from an influx of data on rainfall, temperature, and soils from the 1930s to the 1950s.

However, the commitment of the Soviet state under Stalin to grow a large station network did not extend to seriously financing meteorological and climatological research. After the Great Patriotic War, the interpretation of drought data lagged badly behind their production and collection. Meteorologists lacked the technical means to build upon this data. In education,

meteorological knowledge and climatology did not enter the agronomic curriculum.^{xli} Worse still, from 1941 until at least 1952, Soviet higher education had no program for agrometeorology, which created a severe shortage of qualified personnel.^{xlii}

After the drought of 1946 Soviet meteorologists saw in Stalin's "Plan for the Transformation of Nature" an opportunity to deepen work on droughts in the southeastern part of European Russia.^{xliii} The idea behind the Plan and other "great construction projects of communism"—first and foremost the massive hydroelectric and canal schemes on the Volga, Don, and Dnepr Rivers—was to transform the nature (climate, water, plants, and soils) of the drier regions of southern parts of European Russia, northern Caucasus, southern Ukraine, and the Crimea to make it wetter and more amenable to agriculture.^{xliv} The Soviet Hydrometeorological Service was called in for expertise and investigation on the effect of forest shelterbelts on climate, on the impact of dams on air humidity, and other practical issues.

This positive effect on research notwithstanding, the Plan favored the diffusion of erroneous conceptions of drought. Two ideas were especially detrimental to understanding the nature of drought and imagining effective ways to mitigate it: first, the preconception that droughts occur on the Volga and in Ukraine when dry winds (*sukhovei*) bring warm air from Central Asia. In 1959 Davitaia published a paper in an agronomic review in which he debunked the idea that drought was imported from the deserts, an idea that, he claimed was still profoundly entrenched in agronomic circles.^{xlv} Mariia Zavarina had shown that *sukhovei* were driven by the drought-producing anticyclone itself and were not coming from outside the drought region. But because the air masses move clockwise in an anticyclone, the *sukhovei* blow from the east and southeast in the Lower Volga when a drought-bringing high nests above Stalingrad, giving the impression that they come from Kazakhstan.^{xlvi}

Second, the theory of the “breath of the desert”—which was fueled by a vague, crooked parallel to nomadic incursions into historic Muscovy—led to the central phony idea in the Plan: that to prevent the desiccating easterlies from Central Asia and Kazakhstan from entering the steppes of European Russia and Ukraine, the state had to build “ramparts” (*zaslony*): forest shelterbelts, up to one hundred meters deep and nine hundred kilometers long, extending on both shores of the Ural, Volga, and Don Rivers to stop the winds.^{xlvi} The Plan and other “great construction sites of communism” focused on immense infrastructures (shelterbelts, networks of canals, cascades of hydroelectric dams) built using Gulag prisoners and extracting corvée labor from famished peasants, diverting financing and attention from long-known effective measures to mitigate drought at the level of the field and the farm. The Plan misrepresented and misused the recommendation to plant trees to protect fields, which Dokuchaev and Vladimir Sukachev had theorized.^{xlvi}

When the post-Stalin leadership scrapped the plan to transform nature and launched the VLC, scientific understanding of drought in the eastern part of the Soviet Union and meteorological training among agronomists were insufficient. Although equipped with a large observation network and state-of-the-art theorization of atmospheric circulation and global heat and moisture balance, Soviet meteorologists and climatologists had no explanation for and no systematic data on droughts in the eastern part of the USSR (east of the Ural mountains), that is, in the regions where the VLC was to unfold. For their part, agronomists were mostly ignorant of contemporary meteorological research.

The campaign started without serious preparatory climatological studies about the regions to be put under the plow. Geographical study of the lands began with plowing, too late to influence the campaign. The main institutions for climatic research sent out expeditions of post-

graduate students and seasoned scientists to accompany and advise settlers: the Main Geophysical Laboratory, the State Hydrological Institute, the Central Forecasting Institute, and Academy of Sciences' Geography Institute were present from the spring of 1954. Their first major scientific report came out at the end of 1955 when the campaign had already plowed up thirty million hectares. It was a general description of northern Kazakhstan's and western Siberia's physical geography without practical information about drought origin, occurrence, and patterns in these regions. A short chapter on drought written by M. S. Kulik followed a chapter on frosts—a real, although far lesser problem in this region—and gave little data or advice. The book did not acknowledge the centrality of drought in the Virgin Lands (VL), comprising dry and hot winds, dust storms, and periods of deficit rainfall over several seasons or years.^{xlix} The knowledge about drought accumulated by local farming communities already living in the VL before 1954 was ignored by both the New Landers and the scientists.¹

I have shown elsewhere that knowledge about specific natural conditions and the risks they posed to wheat monoculture in the VLC regions developed only in the 1960s, after the settlers had plowed forty million hectares in the steppes and after the first serious setbacks and harvest failures at the turn of the 1960s began endangering Khrushchev's rule. Although wind erosion (deflation) and especially its extreme manifestation, dust storms, had long blighted steppe agriculture, research began only when Moscow perceived significant political ramifications.^{li} The same is true of drought research. Four years after the start of the VLC, leading Soviet meteorologists published state-of-the-art studies on droughts in an important edited volume. None of the papers handled the eastern USSR and Central Asia where the campaign was at full throttle. In his paper, leading drought researcher Selianinov explained that he had no data for droughts east of the Urals Mountains.^{lii}

The situation improved only at the turn of the 1960s, when Kazakhstani climatologists Anatolii Uteshev and M. Kh. Baidal tackled statistical and physical studies of drought and their work became known at the Soviet level. Uteshev published the first systematic characterization of Kazakhstan's climate in 1959. One chapter analyses three meteorologically typical situations during which drought occurs in Kazakhstan. One drought condition strikes central Kazakhstan when a latitudinal type of atmospheric circulation dominates in Russia and Kazakhstan: highs drift slowly from west to east over central Kazakhstan, squeezed between lows to the north (northern Urals and the Kara Sea) and to the south (over Lake Balkash and the Tian Shan range). Second, like the Lower Volga, western Kazakhstan is subject to drought during the East European type of circulation, if an anticyclone from the White Sea descends toward the Caspian Sea, as Mul'tanovskii had shown. Last, droughts occur in eastern Kazakhstan when the western Siberian type of circulation brings cold dry air masses from the northeast to the Altai Mountains (the rest of Kazakhstan then is under strong cyclones).^{liii} Uteshev published the first fundamental monograph on droughts in Kazakhstan in 1972, two years before the VLC's twentieth anniversary, after more than a decade of devastating dust storms and several crop failures.^{liv}

The first half of the 1960s had been marked by a major erosion crisis in the VLC, which contributed to Khrushchev's ouster in October 1964. The steppes of northern Kazakhstan and western Siberia had turned into a "Soviet Dust Bowl," contributing to food shortages across the country.^{lv} The party first secretary, who had built his legitimacy on finding a definitive solution to the bread issue, had to import wheat from Canada in 1963 and announce it publicly, a major humiliation for the Soviet leadership which probably saved the population from a serious food crisis.^{lvi} In Kazakhstan, yields per hectare diminished by 90 kilograms (-14.5 percent) in the first half of the 1960s compared to the second half of the 1950s.^{lvii}

The insufficient understanding of the steppe climate and the ignorance of the knowledge that was already available facilitated the party's insistence on raising production every year regardless of the economic situation of the farms, the state of the soils, or the availability of seeds, labor, machinery, and chemicals. The will to quickly produce extraordinary results—to make the Virgin Lands the new breadbasket of the country, to solve the problem of meat production, and to show to the world that Soviet agriculture was the most productive and effective—led to relentless expansion of the sown surface. Wind erosion and dust storms damaged millions of hectares because marginal lands, easily salinized soils, and light, pulverizable soils had been plowed under political pressure. Until at least 1963, the policy imposed by the party hierarchy on the farms was to acquire more lands to compensate for diminishing yields per hectare because of erosion and drought, leading to still more erosion and vulnerability to low rainfall. The “Soviet Dust Bowl” was clearly human-made. Water deficiency in the first half of the 1960s could not account for the crop failures and resulting food crisis. Erosion provoked by soil mismanagement explains the bad harvests and Khrushchev's unfortunate decisions explain the food crisis.^{lviii}

<H1>Scientific Explanations for the Drought Crisis of the 1970s

<TX>In the 1970s, many Soviet scholars were convinced that the climate was becoming more arid. A series of severe droughts challenged climatologists, pedologists, and agronomists for explanations. The political leadership under Brezhnev needed to explain to the population why food provisioning was faltering. Leading agronomists, climatologists, and soil scientists came up with theories to interpret the succession of droughts.

After Leonid Brezhnev replaced Khrushchev, a series of years with favorable weather, high investments, and better central management of agriculture allowed the Virgin Lands to

recover from the crisis. However, the second decade of Brezhnev's rule was marked by an unusual series of dry years and a protracted food crisis. Drought hit central Russia in 1972 and provoked well-remembered peat and forest fires. The Virgin Lands were hit by drought two years in a row, in 1974 and 1975. Three years in a row—1979 to 1981—were disastrous across the country, and 1984 was very dry.^{lix} The droughts of 1975 and 1981 rank among the most severe of the century on Soviet territory.^{lx} The severe droughts of 1963, 1975, and 1984 encompassed all main grain regions.^{lxi}

Khrushchev and Brezhnev hid behind “natural disasters” to draw attention away from the consequences of their agricultural policy. Khrushchev said at a Central Committee plenum in 1953 that first there was a “severe winter, and then a fierce drought has caused damage to the most important agricultural regions of the country.”^{lxii} Again in 1963, to justify importing Canadian wheat, Khrushchev blamed the dry weather.^{lxiii} Speaking with Kazakh comrades in Alma-Ata, Brezhnev exaggerated boldly: “Last year [1972] due to the drought that encompassed three-quarters of our country, we had to overcome many difficulties. According to scientists' data there wasn't such a drought in the last hundred years.”^{lxiv} In fact, Kazakhstan and the eastern USSR were spared by the 1972 drought, which concentrated on the European part of the USSR.

Scapegoating low-rank party functionaries was another technique used by party leaders to account for crop failures. After a decade of droughts, Brezhnev in 1982 accused farm managers and party functionaries of not sticking to the right agricultural practices. The Politburo threatened them with retaliation if they would not respect the prescribed timing for sowing.^{lxv}

Many agronomists did not buy into the “natural disaster” rhetoric. For the academic Alexander Baraev from VASKhNIL (the All-Union Academy of Agricultural Sciences of the Soviet Union), who led a major research institute on grain farming in northern Kazakhstan,

disastrous crop failures were by no means inevitable. He wrote a lengthy memo to the government in 1976 promoting the soil-protecting farming technologies his institute had tested for steppe agriculture. He refused to define drought as a disaster: “Often one tries to account for the low crop capacity in grain and the strong reduction in gross grain yields in certain years by ascribing them to a natural disaster [*stikhiinoe bedstvie*]: drought and sukhovei. However, such explanation is not objective. In fact extremely dry years in the steppe regions of our country are an inevitable phenomenon, independent from the will of man and, we could say, normal.”^{lxvi}

Remarkably, Baraev refuted the climatic argument just one year after a drought had devastated both the Asian and European parts of the country. Dry years in the Kazakh steppe were not droughts, he wrote, but a regular feature of the semi-arid and sub-humid climates. Distinguishing between drought and aridity, the former was a human-made problem.

In his memo, Baraev defended the soil-conserving farming system he had devised in the first half of the 1960s under the influence of Canadian agronomists and farmers. The basis of the system was to leave fallow one-fourth of the tith each year. To Khrushchev, removing such a significant amount of land from sowing (and so from harvest) was unacceptable. After two clashes in Kazakhstan over the fallow issue, he almost removed Baraev from his post as director of an agronomic institute near Tselinograd (now Astana). After Khrushchev’s removal Baraev’s farming system received Moscow’s blessing: he was named an academician of VASKhNIL and received two Orders of Lenin; his institute was promoted to be the central scientific hub for dry farming in the steppes east of the Urals.

Despite Moscow’s support, however, Baraev’s set of rules to spare soils under wheat monoculture was not unanimously enforced even in northern Kazakhstan. The fallow requirement posed a threat to farm managers and regional leaders laboring to meet the

production plan. During the drought years of the first half of the 1970s, some Kazakh grain regions decided to cultivate all fallow lands in order to maintain production. Kustanai oblast (province) forbade bare fallows in 1974–1976, and Severo-Kazakhstanskaia oblast did the same in 1975. Unfortunately, cultivating fallows proved disastrous: yields fell in these two regions, despite their having the richest soils in Kazakhstan. Recovery would take years, Baraev warned.^{lxvii} He tried to convince the political leadership that rotation with 25 percent of land laying fallow would yield more grain than land cultivated without fallow, given the yearly oscillation of production and the quantity of seeds.^{lxviii} For Baraev the arid conditions of the steppes challenged agronomists and peasants to look for coping strategies, especially agro-technical systems; blaming the weather for the dry years was infantile and irresponsible.

In contrast to Baraev many climatologists had begun to reject the view that climate was a stable and unchanging feature of the environment. For Baraev, steppe climate was stable in the sense that it was best understood as a succession of dry and wet years, even if science could not yet explain or predict such oscillations. He theorized that two of every five years were highly dry in Kazakhstan. The occurrence of two droughts within five years (1972 and 1975) in the steppes west of the Urals was for him proof of the regularity of steppe climate.^{lxix} But Soviet climatologists, in tune with their colleagues around the world, worried that the climate itself was becoming more arid. Contrary to Baraev, the sequence of droughts in 1972 and 1975 shocked Drozdov as abnormal. He classified them as the worst of the century and calculated the probability of two such severe droughts in a half decade was one in thirty-eight thousand years. For him climate warming could not sufficiently explain the growing occurrence of droughts and the aridization of steppe climate.^{lxx} He found that farming had modified the climate of the steppe. In comparison to the original grass steppe, evaporation is reduced in the spring on fallow land

and on sown surfaces until sprouting. Consequently, precipitation is reduced on millions of hectares of recently cultivated lands, increasing the probability of droughts.^{lxxi}

For meteorologist Mikhail Budyko, the industrial and agricultural activities of humankind brought changes in the global climate.^{lxxii} He forecast a global increase of temperatures in the 1970s because of human activity.^{lxxiii} Since the middle of the twentieth century, economic activities had had the same quantitative impact on temperature change as its natural oscillation, he wrote. The warming process, boosted by energy consumption and the greenhouse effect, materialized in rising surface temperature at the end of the 1960s. Two severe droughts had struck the USSR in the first half of the 1970s alone, confirming the prediction of decreasing humidity and increasing temperatures, Budyko claimed in 1977. Temperatures would further rise, and rapidly, he warned, bringing about economic disruption.^{lxxiv} Within just a few decades the earth would return to the carbon dioxide concentration it last reached in the Tertiary Period, millions of years before. The temperature increase, already destructive in the 1970s, had the potential to bring about a “global ecological crisis” like the one announced in the famous report to the Club of Rome, *Limits to Growth*, published five years earlier.^{lxxv} For the dry steppes in particular, climate change promised duress: one could expect more regular and marked anomalies in temperature and precipitation. The effect of the reduction of precipitation on agricultural zones with irregular humidity like the steppes—and on bodies of water—increasingly worried Budyko.^{lxxvi}

Some meteorologists pointed out one probable positive consequence of global warming for Soviet agriculture: with the increased concentration of carbon dioxide, the physiological capacities of plants would grow, and rising temperatures would extend and warm the vegetative period, leading to increased yields. However, these meteorologists warned that the anticipated

diminution of precipitation would probably bring about disturbances in the distribution of yields in time and an increase in extreme dry events.^{lxxvii} The main forecast for the steppes and forest steppes remained pessimistic among meteorologists in the 1980s. The prognostication made by Budyko at the beginning of the 1970s seemed to have become reality: according to his aridity index, the conditions of humidification in the main crop-growing regions deteriorated markedly in 1975–1985 in comparison to 1964–1974.^{lxxviii} From the second half of the 1960s, wheat yields stagnated at 1,400–1,500 kilograms per hectare, but with considerable anomalies and amplitudes.^{lxxix}

Pedologists shared the climatologists' concern about the drought wave of the 1970s. They argued that the growing number of droughts and crop failures and the destruction of vegetation and soils were linked. Among them, Viktor Kovda, renewing a century-old debate among Russian geographers, elaborated on the idea that the steppes of the Soviet Union were desiccating. Kovda had played a key role in the international desertification debate triggered by the 1972 Sahel drought. At the turn of the 1980s, Kovda was unsure whether the high climatic variability and repeated droughts he witnessed in the Northern Hemisphere meant that the climate was warming or cooling. But he was certain that a general arid trend animated the climate, which in his understanding could be linked to either a colder or a warmer climate.^{lxxx}

In a monograph published in 1977 and translated into English three years later, Kovda built on George Kukla, Hubert Lamb, and a 1975 report of the US Academy of Sciences on climate change, all warning that a new global cold era was on its way.^{lxxxi} He shared Kukla's and Lamb's views that the Northern Hemisphere was probably entering a new Little Ice Age, but he rejected the latter's sun spot theory.^{lxxxii} Instead, Kovda used geological cycles that had been uncovered by A. Shnitikov in 1957: ice, peat, climate, and ocean data revealed moisture cycles of

approximately eighteen hundred years for the Northern Hemisphere. The last of these cycles began in the thirteenth century and had entered its cooling and dessicating phase in the nineteenth century. He insisted that in the Holocene, periods of warming were coupled with greater precipitation; conversely, cool periods and aridization—or xerotization—due to decreased precipitations were linked. To him, the diminishing global air surface temperatures of the 1960s and 1970s signified that the multi-secular cooling and aridizing trend had resumed after a short interval in the 1930s–1950s. He diagnosed a slow tectonic rise of water-accumulative plains around the world with severe consequences for soils, waters, and vegetation: subsoil waters became less accessible to the plants, the hydrological network cut deeper, and the snow limit receded.^{lxxxiii} Although the main force behind aridization was geological, Kovda stressed how human activity reinforced the trend toward a more arid climate: heightened groundwater usage, the acceleration of runoff, deforestation, and the destruction of grass vegetation for agriculture all “contributed to the lowering of the water table.”^{lxxxiv}

The droughts of the 1970s and the bad results of Soviet agriculture prompted earth scientists to find explanations. Those reviewed here represent some of the most important among them at the time. Their differences testify to the diversity of scientific approaches to drought and climate and to the lack of a convincing explanatory scheme for the perceived growing occurrence of heat waves. Underpinning their theories were both a century-old thread of thought about climate change among Russian thinkers and the participation of Soviet scientists in international debates about global warming, global cooling, and desertification.^{lxxxv} Remarkably, all of them made room both for natural and human factors, letting them act at different chronological and geographical scales—from microclimate and pedological change via farming to global climate change via greenhouse effect.

The alarm rung by Soviet earth scientists in the 1970s and 1980s might have been exaggerated. Thirty years later climatologists find that farming conditions actually improved in the last quarter of the twentieth century in the grain-growing regions of Russia and Kazakhstan. Oleg Sirotenko and Vera Pavlova find that the climate became less arid in the Russian steppes after 1975.^{lxxxvi} Like Budyko and Drozdov, they see the temperatures growing, but this growth went hand in hand with more rainfall—a correlation reminiscent of Kovda’s view on aridization. All in all, Russian climate has become less continental, with the vegetative season gaining two weeks in the second half of the twentieth century.^{lxxxvii} In a reversal of what their predecessors and colleagues concluded, they find that everywhere except in central Russia a better climate has contributed to rising yields.^{lxxxviii} Retrospectively, it appeared that, when comparing 1966–1995 to 1936–1965, climate change had actually led to a warmer vegetative period and to increased precipitation in the main grain-growing regions of the former USSR (Kazakhstan, Russia, and Ukraine). Thus, the climatic conditions for growing crops improved markedly, contrary to the diagnoses of the 1970s and 1980s.^{lxxxix}

<H1>Conclusions

<TX>Russian and Soviet earth scientists have demonstrated a strong interest in drought and climate change since the nineteenth century. Historians have demonstrated they played an important role in describing global atmospheric circulation and theorizing the climate system.^{xc} In this article I have shown that their theories of climate change were linked to their observation of droughts in the main grain baskets of Russia, Ukraine, and Kazakhstan. Crop failures triggered research on droughts. Studies of atmospheric droughts nurtured scholarly reflection on changes to the steppe climate. In the 1970s repetitive droughts resurrected a century-old supposition that the steppe climate was becoming more arid. Scientists devised several theories

to account for the desiccating change in the climate of the steppes. They diagnosed the temperature increase as a product of global warming, as Budyko demonstrated. But trends in precipitation are more difficult to distinguish and assess. It appears now that levels of precipitation have increased in most steppe regions. Thus, Russian meteorologists nowadays estimate that—notwithstanding the droughts—the climatic conditions of Soviet agriculture have improved since the 1960s, not worsened.

These meteorological findings tend to indicate that the stagnation of agriculture and bad harvest results from the second half of the 1970s and in the 1980s cannot be adequately understood from climatic data. Instead, the causes should be sought in the agronomic and economic functioning of dry farming in the steppe *sovkhozy*. Drought and crop failures are the result of complex interactions between human and natural entities and processes. The soil—heavily and widely altered by wheat monoculture—is an especially important component of this system. It is time for an “ecologically informed history” accounting for soils, climate, plants, technologies, and humans to reassess the constraints and results of Soviet dry farming in the steppes.^{xci} Soviet agriculture remains understudied. We lack convincing explanations of its challenges and outcomes, which the study of climate alone does not provide. A localized study of how *kolkhozy and sovkhozy* survived—or not—the natural, economic, and political constraints could well advance our knowledge in this field.

<NHD>Chapter 5: Desiccated Steppes

<UNN>Research for this article has been made possible by a grant of the French National Research Agency (ANR) and the German Research Foundation (DFG) for the project “Contemporary environmental history of the Soviet Union and the successor states, 1970-2000. Ecological globalization and regional dynamics” ([ANR-13-FRAL-0003](#), EcoGlobReg, 2014-2018).

<NTX> Martin McCauley, *Khrushchev and the Development of Soviet Agriculture: The Virgin Land Programme, 1953–1964* (Holmes and Meier, 1976); Nikolai Dronin and Edward G. Bellinger, *Climate Dependence and Food Problems in Russia, 1900–1990: The Interaction of Climate and Agricultural Policy and Their Effect on Food Problems* (Central European University Press, 2005), 171–217; Zauresh G. Saktaganova, *Istoriya osushchestvleniya sovetskogo opyta ekonomicheskoy modernizatsii v Kazakhstane (1946–1970)* (Izdatel'stvo KarGU, [[QUERY: not in frontmatter list, OK?—please check. OK so]] 2004), 143–76.

ii

These regions made up 65 percent of plow land, constituted two-thirds of the rich black soils *chernozem*, and produced one-half of the overall agricultural production of the USSR.

Aleksandr Aleksandrovich Nikonov, *Spiral' mnogovekovoy dramy: agrarnaya nauka i politika Rossii (XVIII—XX vv.)* (Entsiklopediya rossiyskikh dereven, 1995), 389.

iii

I. E. Zelenin, “Agrarnaya politika N. S. Khrushcheva i sel’skoe khozyaystvo strany,” *Otechestvennaya istoriya* 1 (2000): 84; Dronin and Bellinger, *Climate Dependence*, 176, 257, 278.

iv Stephan Merl, “Why did the attempt under Stalin to increase agricultural productivity prove to be such a fundamental failure ? On blocking the implementation of progress in agrarian technology (1929-1941)”, *Cahiers du monde russe* 57, no. 1 (2016): 191-220.

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Dronin and Bellinger, *Climate Dependence*, 6, 9.

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vii

For overviews of works centered on vulnerability, see Phil O’Keefe, Ken Westgate, and Ben Wisner, “Taking the Naturalness out of Natural Disasters,” *Nature* 260, no. 5552 (April 15, 1976): 566–67; [[NOTE: now is the time to check all your website addresses to make sure they are still functioning. If not, then we need a note “no longer available, last accessed...” and the date. Or some such.]] Anthony Oliver-Smith, “Anthropological Research on Hazards and Disasters,” *Annual Review of Anthropology* 25 (1996): 303–28; Sandrine Revet, “Penser et affronter les désastres: un panorama des recherches en sciences sociales et des politiques internationales,” *Critique Internationale* 52, no. 3 (2011): 157–73.

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Claude Meillassoux, “Development or Exploitation: Is the Sahel Famine Good Business?” *Review of African Political Economy* 1, no. 1 (1974): 27–33, provides a Marxist view of the Sahel famine as a neocolonial disaster. The landmark in the transformation of disaster studies is Rolando García’s [[QUERY: later set with accent—which is correct?]] project “Drought and Man: The 1972 Case History,” with three volumes published in the 1980s: *Nature Pleads Not Guilty: The 1972 Case History* (Pergamon Press, 1981); *The Constant Catastrophe: Malnutrition, Famines and Drought* (Pergamon Press, 1982); Rolando Victor García [[QUERY: earlier set without accent—which is correct? (without accent in the text)]] and Pierre Spitz, *The Roots of Catastrophe* (Pergamon Press, 1986).

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García [[QUERY: check throughout]] , *Nature*, xii.

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<http://drought.unl.edu/DroughtBasics/WhatisDrought.aspx/>.

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Donald A. Wilhite and Michael H. Glantz, “Understanding the Drought Phenomenon:
The Role of Definitions,” *Water International* 10, no. 3 (1985): 111–20.

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García, *Nature*, 169.

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néolithique à la crise contemporaine* (Éditions du Seuil, 2002).

xvi Christophe Bonneuil and Jean-Baptiste Fressoz, *The Shock of the Anthropocene: The
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Paul R. Josephson, *Industrialized Nature: Brute Force Technology and the
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John L. Brooke, *Climate Change and the Course of Global History: A Rough Journey* (Cambridge University Press, 2014).

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Donald Worster, *Dust Bowl : The Southern Plains in the 1930s*, twenty-fifth anniversary edition (Oxford University Press, 2004).

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On high modernism see James Scott, *Seeing like a State: How Certain Schemes to Improve the Human Condition Have Failed* (Yale University Press, 1998). On nature's agency see Andy Bruno's paper in this volume.

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Marc Elie, "The Soviet Dust Bowl and the Canadian Erosion Experience in the New Lands of Kazakhstan, 1950s–1960s," *Global Environment* 8, no. 2 (January 1, 2015): 259–92.

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Anatoliy Sergeevich Uteshev, "K probleme issledovaniya i prognozirovaniya zasukh," in *Zemel'nye resursy mira, ikh ispol'zovanie i okhrana* (Nauka, 1978), 145.

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Oleg Alekseevich Drozdov, *Zasukha i dinamika uvlazhneniya* (Gidrometeoizdat, 1980), 5.

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Davitaia, “Zasukhi,” 57.

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Drozdov, *Zasukha*, 5–6.

xxxi Ted Steinberg, *Acts of God. The Unnatural History of Natural Disaster in America* (Oxford University Press, 2006)

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Richard R. Heim, “Drought Indices. A Review,” in *Drought: A Global Assessment*, ed. Donald Wilhite (Routledge, 2000), 1:164; E. I. Khlebnikova, T. V. Pavlova, and N. A. Speranskaya, “Zasukhi,” in *Metody otsenki posledstviy izmeneniy klimata dlya fizicheskikh i biologicheskikh sistem* (Rosgidromet, 2012), 144.

xxxiii Dronin and Bellinger, *Climate Dependence*. Stephen G. Wheatcroft, “The Significance of Climatic and Weather Change on Soviet Agriculture (with Particular Reference to the 1920s and the 1930s),” CREES Discussion Paper Soviet Industrialisation Project Series (SIPs) no. 11 (Centre for Russian and East European Studies, University of Birmingham, 1977)

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I. G. Gringof, V. V. Popova, and V. N. Strashnyi, *Agrometeorologiya* (Gidrometizdat, 1987).

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Selianinov, "Proiskhozhdenie," 16; Khlebnikova, Pavlova, and Speranskaya, "Zasukhi," 128.

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The increase was from 150 stations in 1915 to 1,500 in 1928. A. D. Kleshchenko and I. G. Gringof, eds., *Razvitie sel'skokhozyaystvennoy meteorologii v Rossii*, 2nd ed. (Rosgidromet, 2009), 57–58, 60.

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The Russian Drought Monitoring Center uses the HTC for its ten-day summary evaluations of drought conditions. Tsentr monitoringa zasukhi, Vserossiiskii nauchno-

issledovatel'nyi institut sel'sko-khoziaistvennoi meteorologii (VNIICXM), "Dekadnyi Byulleten,'" *VNIICXM*, online at <http://cxm.obninsk.ru/index.php?id=200/>

. Dronin and Bellinger, *Climate Dependence*, uses the HTC index to draw maps showing which regions were affected for every severe drought in Russia and the USSR since 1891.

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G. T. Selianinov, "O sel'skokhozyaystvennoy otsenke klimata," *Trudy po sel'skokhozyaystvennoy meteorologii*, no. 20 (1928): 165–77. The formula is written: <EQU>.

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Kleshchenko and Gringof, *Razvitie*, 75.

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Viktor Abramovich Kovda, *Velikiy plan preobrazovaniya prirody* (Izdatel'stvo Akademii nauk SSSR, 1952), 62–73.

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Davitaia, “Zasukhi.”

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Feofan Farneevich Davitaia, *Zasukhi v SSSR i nauchnoe obosnovanie mer bor’by s nimi po prirodnym zonam* (Izdatel’stvo Ministerstva sel’skogo khoziaistva SSSR, 1958).

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On the debate around the planting of trees in the steppe in tsarist Russia, see David Moon, *The Plough that Broke the Steppes Agriculture and Environment on Russia’s Grasslands, 1700–1914* (Oxford University Press, 2013).

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Anatoliy Sergeevich Uteshev, ed., *Klimat Kazakhstana* (Gidrometeorologicheskoe izdatel’stvo, 1959), 117–38.

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Anatoliy Sergeevich Uteshev, *Atmosfernye zasukhi i ikh vliianie na prirodnye iavleniia* (Nauka, 1972).

lv Khrushchev had taken many fatal decisions regarding agriculture in the first half of the 1960s.

lvi McCauley, *Virgin Lands*, 82, 99. Dronin and Bellinger, *Climate Dependence*, 176.

lvii

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Dronin and Bellinger, *Climate Dependence*, 251, 295–300, 304.

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Dronin and Bellinger, *Climate Dependence*, 303.

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“O nauchnykh osnovakh zemledeliia v stepnykh raionakh SSSR v desiatoi piatiletke i rasshirenii proizvodstva protivooerozionnoi tekhniki,” 1975 (GARF f. R-5446, op. 110, d. 932, l. 13).

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GARF f. R-5446, op. 110, d. 932, ll. 9–11.

lxviii

GARF f. R-5446, op. 110, d. 932, ll. 18–19.

lxix

GARF f. R-5446, op. 110, d. 932, l. 13.

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Drozdov, *Zasukha*, 61–62.

lxxi

Drozdov, *Zasukha*, 63–67. He calculated a reduction in precipitation of 17.4 percent.

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Mikhail Ivanovich Budyko, *Sovremennye izmeneniia klimata* (Gidrometizdat, 1977), 5, 43.

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Budyko, *Sovremennye izmeneniia klimata*, 39, 40, 43.

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G. V. Menzhulin and S. P. Savvataev, “Vliianie sovremennykh izmeneniy klimata na urozhaynost’ sel’skokhoziaistvennykh kul’tur,” in *Problemy atmosfernogo uglekislogo gaza. Trudy sovetsko-amerikanskogo simpoziuma. Dushanbe, 12–20 oktiabria 1978g.* (Gidrometizdat, 1980), 186–97.

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