Advanced Review

Climate modification and climate change debates among Soviet physical geographers, 1940s–1960s†

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This review provides an insight into some of the main themes characterizing the work of Soviet physical geographers concerning climate during the decade following the Second World War. Post-1945, pressure was placed upon geography via the state and the Academy of Sciences to ensure that its activities were of practical use to the development of the socialist economy and this was particularly evident in the case of work related to climate and climate modification. The review is divided into four main sections. First, it provides an understanding of the range of work carried out by physical geographers with respect to climate and related phenomena in the late 1940s and 1950s. Second, it focuses on the work of geographers and climatologists in relation to the heat and water balance at the earth's surface, which attracted considerable attention within geographical circles as well as more broadly within Soviet science during the 1950s. Third, it reflects upon the way in which Soviet geography utilized its understanding of climate systems in order to participate in national schemes concerned with the modification of the climate and the transformation of nature. Finally, the review highlights the maturing of climate modification debates among geographers and cognate scientists during the late 1950s and early 1960s with the emergence of competing discussions over the potential for human activity to result in both positive and negative consequences for the global climate system.

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INTRODUCTION

Understandings of climate and climate modification were relatively advanced in the Soviet Union, founded on a long and celebrated history of conceptual and empirical work in this general area.[1] The sophistication of such work can be related, in part at least, to the particularities of the climatic conditions afflicting the Russian landmass. As noted by the specialist on Soviet climatology, Paul E. Lydolph,

> In general, the country lacks heat. And where heat becomes more adequate, it lacks moisture. It is little wonder, then, that the Soviets have bent every effort to investigate ways of wringing every drop of moisture and every calorie of heat from their meager climatic storehouse.... Operating under such pressures of necessity, Soviet climatology has reached high levels of achievement. (Ref 2, p. 1)

This review aims to provide an insight into the main themes characterizing the work of Soviet physical geographers concerning climate during the decade following the Second World War. I have suggested elsewhere that three broad trends were discernible in the geographical literature during this

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period; namely, notions of climate as a complex and dynamic natural phenomenon, climate as both knowable and modifiable, and finally a growing body of work reflecting on the influence of human activity on climate systems.[3] This paper picks up on elements of these three main trends in order to provide greater detail. A key aspect of the review focuses on the work of geographers related to climate modification which was in part linked to a broader agenda concerning the state-sponsored transformation of nature. It is posited that initiatives in this area were driven forward to a large extent by political pressures emanating from both the Party and the Academy of Sciences to ensure that geographical science was of practical use to the development of the socialist economy. More generally, Stalin had made significant interventions in a range of scientific debates such as philosophy, physics and biology post-1945 as part of a deliberate move to position Soviet science in competition with the West and in order to demonstrate its superiority (Ref 4, pp. 4–6). Linked to this, Soviet science was expected to assist in the advancement of socialism,[5] and the geographical sciences were caught up in the resultant burst of activity. At the same time, Soviet geography was not considered a discipline of high strategic value and therefore received less overt attention than areas such as biology (Ref 5, pp. 54–83). While considerable emphasis was placed on the positive aspects of socialism with respect to scientific advancement, it is important to recognize that geographers also drew upon long-standing work concerning climate traceable to the prerevolutionary period. Before proceeding, it is also worth reflecting a little more on the nature of the interaction between Soviet and Western scientists working in the area of climate. The focus of the paper ensures that the influence of Soviet climate science on the West is to the fore. However, while the post-1945 period was characterized by intense competition between East and West in many areas of the natural sciences, it was also underpinned by episodes of intellectual exchange driven forward by large-scale initiatives such as the International Geophysical Year (1957–1958). Furthermore, while international travel was severely restricted for many in the USSR, certain Soviet scientists were able to travel widely during this period in order to attend conferences and associated intellectual gatherings, thus facilitating a deep engagement with Western science. Such activity tended to increase following the death of Stalin in 1953 and with the formalization of East–West cultural relations in the late 1950s and 1960s. With respect to climate science, dominant Soviet climatologists such as M.I. Budyko developed strong intellectual relationships with the West built on notions of reciprocity and mutual respect.[a] Budyko's subsequent publications reflected this exchange citing, for example, a range of Western sources in the bibliography.

The first part of the review provides an indication of the type and range of work being carried out by physical geographers with respect to climate and related phenomena in the late 1940s and 1950s. The following section moves on to focus on the interest surrounding the heat and water balance at the earth's surface acknowledging the considerable importance attached to such work within geographical circles as well as more broadly within Soviet science during the years following the Second World War. Indeed, writing in the early 1970s, Lydolph went so far as to suggest that such work was a defining characteristic of Soviet climatology (Ref 1, p. 640). The third section reflects upon the way in which Soviet geography utilized its understanding of climate systems in order to participate in national schemes concerned with the modification of the climate. Finally, the review notes the maturing of climate modification debates during the late 1950s and early 1960s with the emergence of competing discussions over the potential for human activity to result in both positive and negative consequences for the global climate system.

SOVIET PHYSICAL GEOGRAPHY AND UNDERSTANDINGS OF CLIMATE

There is insufficient space to go into the nuances of Soviet geographical thought and practice during the early post-war period and yet the disciplinary focus of this review requires at least some preliminary comment. An underlying theme of the review is the nature of the link between Soviet geography's position within the broader scientific academy and the character of the climatic work carried out by geographers in the early post-war years. In particular, the emphasis placed on the importance of applied science within the Academy of Sciences ensured that work related to climate modification emerged as a dominant theme during this period. Soviet physical geography produced a significant volume of work related to understandings of climate, yet its contribution has attracted relatively little detailed critique. At a general level, climatology was considered one of several fields within the remit of Soviet physical geography, although simultaneously existing in its own right as a standalone discipline. Lydolph (Ref 1, pp. 637, 660–661) listed eighteen scientific institutions involved in some aspect of climate research by the late 1960s and this included the Soviet Geographical Society and the Institute of Geography, Academy

TABLE 1 | Key Natural Scientists Referred to in the Text

Name	Disciplinary Specialism and Main Affiliation
T.G. Berlyand	Geography; Main Geophysical Observatory, Leningrad
L.S. Berg	Geography; Leningrad University
M.I. Budyko	Climatology; director of the Main Geophysical Observatory, Leningrad
F.F. Davitaya	Agricultural sciences, geography, climatology; director of the Institute of Geography, Tbilisi, Georgia
V.V. Dokuchaev	Soil science; St Petersburg University (pre-revolutionary period)
O.A. Drozdov	Geography, climatology; Head of Climatology Department, Main Geophysical Observatory, Leningrad
I.P. Gerasimov	Geography; Director of the Institute of Geography, Soviet Academy of Sciences, Moscow
A.A. Grigor'ev	Geography; Director of the Institute of Geography, Soviet Academy of Sciences, Moscow
N.P. Rusin	Geography; deputy director, Main Geophysical Observatory, Leningrad
A.I. Voeikov	Climatology, geography; St Petersburg University (pre-revolutionary period)

Source: Ref 1, pp. 637–665.

of Sciences USSR. A further, and key, organization in this regard was the Voeikov Main Geophysical Observatory (GGO) which had been established in 1849 as the Main Physical Observatory and was renamed in 1929 after the pre-revolutionary climatologist A.I. Voeikov. While the GGO furthered research and understanding in many areas, it was not until the Soviet period that 'large-scale meteorological research' was carried out effectively (Ref 6, p. 2). Much of the current review will focus on the work of individuals linked to the GGO and the Institute of Geography (see Table 1). Some indication of the close relationship between Soviet physical geography and other physical sciences is evidenced by the academic journals of this period. For example, a 1947 review article reflecting on the successes of Soviet geography by A.A. Grigor'ev was published in the 'geographical and geophysical series' of the *Proceedings of the Academy of Sciences, USSR*.[7] Indeed, his article was accompanied by a number of other 30-year retrospective reviews concerning the geophysical sciences and this included a paper on climatology by E.S. Rubinshtein, which paid particular attention to the work of the GGO.[8] The Institute of Geography and the GGO would collaborate on a range of issues during the years following the Second World War. A key figure in this respect was A.A. Grigor'ev (1883–1968). He acted as Director of the Institute of Geography from its founding in the 1930s through to 1951 and exerted a significant influence over the direction of physical geography during this period. More specifically, he spent much of the late 1930s and 1940s advancing the object of physical geography as the study of the 'reciprocal penetration of the atmosphere, lithosphere, hydrosphere and biosphere and the processes flowing in them' (Ref 7, p. 377), building on his work concerning the single physical-geographical process. His ideas were subjected to substantial criticism during the late 1940s and early 1950s, and yet he forged productive links with the GGO and the climatologist M.I. Budyko (1920–2001) in particular, of whom more below.

Understandings of Climate among Soviet Geographers: L.S. Berg (1876–1950)

Climate and related natural physical systems had formed an important element of Russian geographical thought and practice since the late nineteenth century, and this emphasis was continued, as well as strengthened, during the early to mid Soviet period.[7] The work of the geographer Lev Semenovich Berg provides a useful starting point from which to consider the nature of such developments. Berg had established his reputation as a leading geographer in the late tsarist period during which time he developed his ideas concerning landscape science among other interests.[9] At the same time, he also published a number of influential articles and monographs concerned with climate and climatic processes during the course of a long career. A 1925 article in the *Proceedings of the Geographical Institute*[10] combined his interest in climate with his ideas concerning geography as a chorological science; that is one concerned with identifying and explaining the spatial variation of natural phenomena at the earth's surface. More specifically, it explored the earth's latitudinal climatic belts with Berg noting at the start of the paper the significance of climate for the distribution of vegetation and soil types as well as economic activity. He identified ten climatic belts or zones associated with the northern hemisphere's land areas moving from the tundra in the far north through forest and

steppe zones and finally sub-tropical and tropical belts. In keeping with Berg's broader work on landscape zones, the belt descriptors tended to reference vegetation explicitly, although he made it clear that these were climatic and not vegetational zones. Whilst acknowledging the tendency for climatic and vegetational zones to coincide, he also noted the fact that vegetation often lagged behind historical shifts in climate and was also influenced in its distribution by other natural factors (Ref 10, p. 121). Berg's 1947 book entitled *Climate and Life*[11] (which was a second and heavily revised edition of a 1922 book) provided an interesting insight into the character of work undertaken by physical geographers during the late tsarist and early Soviet periods with regard to climate. The book had the basic aim to consider the interrelationship between climate and factors such as soil, fauna and vegetation. The 1947 edition included eleven chapters drawing predominantly from his earlier published work and covering a number of broad themes. For example, the second chapter of the book reprinted his paper on 'The question of historical climate change' which had been originally published in the journal *Zemlevedeniya* in 1911, and which provided a detailed examination of the various opinions concerning the apparent desiccation of Ukraine, Central Asia and Mediterranean countries. Indeed, Berg had great interest in exploring climate change within an historical framework. The book also included a significant chapter on the origins of loess formation which advanced an alternative soil-based approach in contrast to the dominant aeolian theory of deposition.[12] A number of more specific themes were covered including an exploration of the purported link between climatic conditions in the Arctic and the changing level of the Caspian Sea. The book's first chapter examined the warming period experienced in the northern hemisphere during the early part of the twentieth century and utilized a range of data in order to explore the extent of this phenomenon in more detail; these included evidence of shifts in bird migration patterns and ice-melt on the river Neva.

Broader Understandings of Climate among Soviet Physical Geographers

The work of Berg was part of a much broader endeavor which encompassed a range of different activities. Indeed, the earlier noted review article by A.A. Grigor'ev, which reflected on developments within Soviet geography during the period 1917–1947, highlighted a number of trends evident within the sub-field of climatology (Ref 7, p. 382). For example, and moving beyond the self-congratulatory bluster, the paper drew attention to work concerning understandings of the climate of the USSR and related map work, advances in agro-climatology, as well as the increased attention devoted to the interrelationship of individual climatic elements in order to provide a deeper insight into atmospheric processes (Ref 7, pp. 382–383). Finally, he noted the work of geographers such as L.S. Berg with respect to understandings of climate change in the recent as well as historical past. A later retrospective of Soviet climatological science from a geographical perspective was provided by O.A. Drozdov in 1970 as part of an edited collection concerning the history of Soviet physical geography. Drozdov, a doctor of geographical sciences who worked in the GGO, opened the chapter with the suggestion that Soviet climatological research had been influenced to date by two main factors encompassing the demands of the planned economy and the more efficient organization of scientific activity in general (Ref 13, p. 29). In the following pages he drew attention to the improvements made to the system of meteorological observation, the production of reference materials, the quantification of climate theory, as well as work concerning the physics of the lower atmosphere which included insight into the heat and water balance and associated classification systems (Ref 13, pp. 29–36). Of the areas highlighted by Drozdov, it is those understandings linked to the heat and water balance at the earth's surface which are of particular interest for the purposes of this review. Indeed, Alisov and Khromov (Ref 14, p. 65) noted that work concerning the heat balance was one of the central areas of concern for Soviet climatology during the 1950s and 1960s due to its purported role in climate formation alongside atmospheric and moisture circulation. Indeed, by the late 1940s, scientific work related to the heat and water balance formed a central part of efforts to modify and transform regional climate across large parts of European Russia within the framework of the Great Stalin Plan for the Transformation of Nature. In the light of the importance of such work, the following section traces the development of related thinking within Soviet physical geography.

HEAT AND WATER BALANCE AT THE EARTH'S SURFACE

The climatologist M.I. Budyko and geographer I.P Gerasimov[b] (1905–1978) delivered a joint paper in 1959[15] at a special symposium concerning 'The heat and water regime at the earth's surface,' which formed part of the Third Congress of the Geographical Society, USSR. The paper was broad in scope and

ambition as evidenced by its title, 'The heat and water balance at the earth's surface, the general theory of physical geography and the problem of the transformation of nature.'[15] Studies concerning the earth's heat and water balance had by this time emerged as a key focal point for Soviet physical geography; indeed, such work had been highlighted as a key task for Soviet science more broadly by the Academy of Sciences in 1954. The importance of the heat and water balance for Budyko and Gerasimov was linked strongly to their understanding of geography's main task at that time, namely for it to provide 'comprehensive scientific service to the great work of humankind with respect to the varied and increasingly intensive utilization of known natural resources and the transformation of nature of already utilized territory' (Ref 15, p. 3). Their paper established the centrality of work concerning the heat and water balance to advancing this aim. More specifically, they stated:

> The main scientific idea underlying the problem under discussion is that the heat and water balance of the earth's surface is, as a rule, the main mechanism that determines the intensity and character of all other forms of energy and matter between the basic components of the geographical environment i.e. the climatic, hydrological, soil-forming, biological etc. phenomena occurring at the earth's surface. (Ref 15, p. 4)

It therefore followed that a careful analysis of the mechanisms underpinning the heat and water exchange would enable 'premeditated and sustainable transformative changes' in the wider environment. Furthermore, they envisaged that in time such understanding would enable large-scale changes to climatic conditions in addition to lower-level and smaller-scale transformations (Ref 15, pp. 16–17).

The Collaborative Work of A.A. Grigor'ev and M.I. Budyko

The intellectual underpinnings of work related to the heat and water balance at the earth's surface had a relatively long history stretching back to the late tsarist period (e.g., Ref 16, pp. 176–77) as a consequence of its relevance for addressing Russia's agricultural problems in the steppe region of European Russia and parts of modern day Central Asia. Whilst characterized by fertile black earth soils, this region was also subject to dry conditions and periodic drought. The earlier work of the climatologist and geographer A.I. Voeikov (1842–1916) and soil scientist V.V. Dokuchaev (1846–1903) is of particular importance; the former with regard to his ideas concerned with large-scale climatic processes[17] and the latter for his work related to both soil-formation and the mitigation of drought conditions in the European steppe region.[18,19] In order to trace some of the key aspects of this work as it developed during the early to mid Soviet period within the geographical sciences, the following focuses on the activities of the geographer A.A. Grigor'ev.

Grigor'ev was a key figure in the development of Russian geography during the early Soviet period and acted as the Institute of Geography's first director following its establishment in the early 1930s. From the mid-1930s onwards, he devoted considerable attention to developing the notion of a single physical–geographical process which he envisaged as a complex natural process binding together a range of natural phenomena at the earth's surface. Underpinned (purportedly) by the tenets of dialectical materialism, Grigor'ev proceeded to explore the balance of energy and matter for each of the main physical-geographical zones (e.g. tropical, temperate etc.) and his key works in this area were published between 1938 and 1956 under the general title 'Sketches of the characteristics of the main types of physical–geographical environment.' Grigor'ev's general approach built self-consciously on the earlier work of Dokuchaev and his school. Indeed, writing in 1956, he noted that '[A]lready in 1900, V.V. Dokuchaev considered that in this respect [i.e. establishing those factors underpinning geographical zonality], of great significance was the distribution at the earth's surface of solar heat and light ... and moisture ....' (Ref 20, pp. 350–351). Furthermore, he went on to suggest that in exploring geographical zonality, Dokuchaev was interested not only in the distribution of heat and moisture but also their correlation via a focus on evaporation rates (Ref 20, p. 351). The specifics of this correlation formed a key feature of Grigor'ev's work as it matured during the 1940s assisted greatly via his collaboration with M.I. Budyko. Indeed, Grigor'ev made reference to the pioneering work of the Main Geophysical Observatory and in particular its initiatives concerned with the yearly radiation balance at the earth's surface helping to determine the energetic base of physical-geographical processes and, latterly, its work concerning the correlation between this yearly radiation balance and the quantity of heat required for the evaporation of the yearly rainfall (Ref 20, p. 351). Importantly, it was shown that the resulting isolines of this correlation corresponded closely with the main physical-geographical zones referred to above.

The links between the Institute of Geography and the GGO appear to have been relatively strong and it is worth reflecting more deeply on the activities of a key interlocutor in this regard, the climatologist M.I. Budyko. Budyko was an influential Soviet climatologist who would later become well-known in the West for his work on climate change as well as more specific aspects of climate systems with a number of his monographs being translated into English (e.g., see Ref 21). He became Director of the GGO in 1954 (a position he held for almost two decades) when just 34 years of age, and he was made a corresponding member of the Academy of Sciences in 1964.[22] In 1950, he published a paper as part of an edited volume celebrating the centenary of the Main Geophysical Observatory entitled 'Climatic factors of the external physical-geographical process,' and this paper aimed to build on the earlier work of Grigor'ev and in particular his suggestion that climatic factors were key to the intensity of the single physical-geographical process (Ref 23, p. 25). He went on to posit that a main area for further research was therefore the character of both heat and water exchange in the physical–geographical 'envelope' (Ref 23, p. 26). Budyko's subsequent work concerning the heat balance at the earth's surface, which it should be noted was developed in tandem with others at the GGO, provided important insight into this general area. Furthermore, while linked to the broader work of Grigor'ev, Budyko was equally sensitive to deeper historical precedents. For example, Budyko, Berlyand, and Zubenok opened their 1954 article entitled 'The heat balance of the earth's surface' with reference to the earlier work of Voeikov who had underlined the potential importance of quantifying the exchange of heat at the earth's surface in order to advance an understanding of climate (Ref 24, p. 17). This multi-authored paper was followed by the publication of a more substantive single-authored monograph by Budyko in 1956 with the same title. While similar work was being carried out in the West, the subsequent publication of Budyko's monograph in English was of great significance because of its underlying methodology and use of data at the global level (Ref 25, p. vii). Indeed, the publication's particular approach towards energy exchanges at the earth's surface was seen as a major boost to the establishment of climatology as a 'more quantitative and physical science' (Ref 26, p. 179). In reviewing this monograph some 40 years later, the British geographer John G. Lockwood noted its significant influence for Western climatology, aided by the English translation. More specifically he noted,

> Budyko showed that energy budget climatology not only provides insights into the causal explanations of the earth's climates but also has wide interdisciplinary implications. These include linkages through the water budget terms to hydrology, glaciology and bioclimatology. (Ref 27, p. 338)

Lockwood ended his review by acknowledging the work's continued relevance, in part at least, for contemporary efforts to model heat exchange at the earth's surface (Ref 27, p. 342).

Budyko's work concerning the earth's heat balance was complemented by two linked papers in the journal *Proceedings of the Academy of Sciences: Geographical Series*, devoted to the issue of the climatic conditions for humidification on the continental mainland[28,29] which explored the interplay between heat and moisture values. Once again, he linked his work to the broader approach of Grigor'ev and the single physical-geographical process (Ref 28, p. 9), but at the same time Budyko and his colleagues moved understanding on in this area by positing a more nuanced link between the moisture conditions at the earth's surface and the size of the radiation balance. More precisely, they determined that 'the size of possible evaporation from the earth's surface for an annual period can be defined by the relationship of the radiation balance of the subjacent surface to the latent heat of evaporation,' which in turn was expressed as a radiation index of dryness[c] (Ref 28, p. 9). The work of Budyko and Grigor'ev in this general area was effectively combined in a jointly-authored 1956 article 'Concerning the periodic law of geographical zonality,' which outlined the value of work concerning the 'radiation index of dryness' in helping to determine the borders between distinct physical-geographical zones. Furthermore, it also enabled the two authors to account for the periodic repetition of key structural features such as soil and vegetation type at different latitudes, linked as they were to the correlation of heat and moisture values rather than the overall size of such factors (Ref 30, p. 131). In his 1977 book *Climates of the Soviet Union*,[2] which formed volume 7 of Elsevier's *World Survey of Climatology*, Paul Lydolph noted the subsequent significance of the joint work of Grigor'ev and Budyko in establishing their influential latitudinal classification of climate types for the USSR (Ref 2, p. 358).[31,32]

GEOGRAPHY, CLIMATE SCIENCE, AND THE TRANSFORMATION OF NATURE

Within the broader context of Stalin's establishment of a distinctive Cold War Soviet science characterized by a reassertion of state control and concomitant

undermining of international scientific linkages,[4,5] the late 1940s and early 1950s were marked by something of a crisis in Soviet geography with respect to its focus and perceived value for the revitalized effort to move Soviet society from socialism to communism. The apparent spur for this crisis was an article written in the propaganda newspaper *Culture and Life* (*Kul'tura i zhizn'*)[5] by K. Vasil'ev entitled 'Out of touch with life' (*V otryve ot zhizni*) and published in 1950.[d] This article was particularly critical of the theoretical work of A.A Grigor'ev and, more broadly, the work of the Institute of Geography. The thrust of Vasil'ev's argument, captured by the title, was that the work of Grigor'ev in particular was somewhat abstract and failed to engage meaningfully with the needs of the Soviet economy as well as society more generally. This particular critique precipitated Grigor'ev's removal as head of the Institute of Geography to be replaced by I.P. Gerasimov and gave rise to a series of articles in the leading geographical journals which reflected on the conceptual weaknesses of Grigor'ev's work as well as his tendency to undermine the work of other geographers.[33]

The Great Stalin Plan for the Transformation of Nature

A key element of the broader critique, i.e. geography's purported limited practical value, was given added significance by the implementation in November 1948 of a major project aimed at transforming large areas of the Soviet Union's south-west region in order to improve agricultural conditions. The decree underpinning the program was entitled 'Concerning the plan for shelterbelt afforestation, the introduction of grass-arable rotation, and the construction of ponds and reservoirs for ensuring high and sustainable harvests in the steppe and forest-steppe regions of European Russia.' The range of activities became known as the Great Stalin Plan for the Transformation of Nature with its central aim to mitigate longstanding issues such as drought that had long afflicted the steppe and forest-steppe regions of European Russia and simultaneously improve the fertility of soil and agricultural productivity. Once again, it is important to note Russia's long-standing historical interest in this issue traceable most obviously to the activities of the soil scientist V.V. Dokuchaev. Indeed, Dokuchaev headed a Special Expedition to the region in 1892 under the auspices of the Forestry Department following a major drought in 1891 with the overarching aim to provide a framework for addressing the recurring drought issue. Such work was interdisciplinary in nature and involved among other things a range of meteorological activities.[34] He subsequently published a monograph, *Our Steppes: Then and Now* (1892)[19], which detailed remedial actions to address the issue. In a similar vein, the scope and complexity of the proposed Stalin Plan ensured that it required input from a number of different disciplines including soil science, hydrology, botany, and climatology. Furthermore, the central role of climatological work at the local and regional scale was clearly evident in the various scientific papers and publications associated with the Plan. Geographers also played a role in such activities; indeed Geography's broad approach to understanding the physical-geographical environment ensured that it had the potential to play a synthesizing role in subsequent discussions and activities related to the Stalin Plan. A 1950 Conference 'Concerning geographical problems linked to the Stalin Plan for the Transformation of Nature'[35] brought together more than forty academic departments and related institutions and consisted of 18 papers devoted to various technical aspects of the Plan including the hydrometeorological effects of protective shelterbelts (M.I. Budyko), possible impact on rainfall in the region (O.A. Drozdov), climate improvement (V.V. Tsinzerling), and a general paper on meteorological research (S.A. Sapozhnikova). More general technical publications were also produced around this time including a 1952 edited collection devoted to the theme of climate change in those areas influenced by the Stalin Plan which covered a range of topics including chapters on changes to rainfall, the thermal regime and moisture levels.[36] F.F. Davitaya[37,38], a specialist in agricultural science as well as a director of the Georgian branch of the Institute of Geography, provided a broader overview of transformative work in the steppe region as part of a retrospective of achievements for Soviet Geography in the early 1960s. More specifically, he reflected on the transformation of nature in the steppe and desert regions via the planting of forest belts, management of snow cover, irrigation activities and the construction of artificial reservoirs. The implementation of the Stalin Plan was undermined markedly by the involvement of Lysenko and his 'nest method' in addition to weak coordination in the field as well as a lack of scientific insight in certain areas, and the initiative was eventually disbanded following the death of Stalin having achieved little of what it set out to do.[39] Nevertheless, it did generate a considerable volume of scientific output concerned with climate modification at the local and regional level. More broadly, the noted shift in emphasis within geography towards more applied work was further reinforced and institutionalized

via a series of resolutions issued by national bodies during the 1950s. For example, in response to this general debate, the All-Union Geographical Society established a series of key tasks at its congress in 1955 which highlighted the central importance of research that was concerned with, among other things, the 'purposeful transformation of natural conditions and the thorough utilization of the elemental forces of nature in the interests of the further increase in the productivity of the socialist economy' (Ref 40, p. 16).

Climate Modification Activities

The events described above helped to shape physical geography's intellectual agenda during the course of the 1950s, placing an emphasis on the application of understanding concerning natural physical systems in order to facilitate the transformation of nature for the advancement of the socialist economy and society more broadly. Allied to this, work devoted to climate modification understandably played a significant role in the ensuing discussions. A semi-popular book entitled *Man Changes the Climate*[41] by Nikolai P. Rusin (climatologist with a doctorate in geography) and Liya Flit (journalist) was published in 1962 (an English-language edition was also published[42]) and this provided an overview of recent work in this area. Perhaps understandably, this particular publication was propagandistic in tone and dwelt on the potential for harnessing advances in science and technology in order to utilize nature in ways beneficial to the national economy (Ref 41, pp. 5–9). Nevertheless, the preface drew attention to two main directions of work related to climate change at the time and these included, firstly, the modification of climate-forming conditions via such activities as drainage, irrigation and afforestation, and secondly, the influence on atmospheric processes such as cloud formation and rainfall, thus resulting in alterations to climate. An English-language bibliographic overview of the significant volume of Soviet scholarly work related to various aspects of climate modification including the seeding of clouds, hail suppression as well as more general work was published in 1967 incorporating papers published over the period 1946–1966.[43] Lydolph[44] provided a further albeit relatively brief English-language overview of both modifications to climate-forming conditions as well as efforts to influence atmospheric processes with respect to agricultural production during the 1950s and early 1960s.

THE EMERGENCE OF A MODERN CLIMATE CHANGE AGENDA

During the late 1950s and early 1960s the interest of physical geographers in the managed and scientifically-based transformation of nature developed into a more expansive engagement with natural resources of which climate resources formed an important element. More specifically, issues concerning the rational use and renewal of natural resources in addition to developing interests in natural protection and pollution started to gain some traction in the scientific literature. Such concerns were given impetus by legal initiatives such as the 1960 'Law concerning the protection of nature RSFSR.' The emerging broad understanding of what nature protection entailed was underlined in the introduction to a 1963 edited collection devoted to the natural resources of the Soviet Union which made reference to both areas of inviolability as well as work concerning the effective integration of natural resources into the national economy (Ref 45, p. 3). Furthermore, the preface went on to suggest that this presented an issue of real substance for geographers and as such was reflected in the Institute of Geography's allied interest in the transformation of nature and resource use (Ref 45, pp. 3–4). The 1963 edition worked through five general resource types including climate. More specifically, it incorporated chapters concerning the influence of agricultural and related activity on climate, atmospheric pollution and wind energy. The chapter by the geographer Ya. I. Fel'dman[46] explored the influence of measures such as large-scale irrigation, forest protection belts and artificial reservoirs on local climate within the context of the aforementioned zonal nature of climatic resources. Furthermore, he noted the need for caution when assessing the links between economic measures and climate in different natural zones,

> A change of the subjacent surface, its ruggedness, radiational and water-heat properties tell on the temperature and humidity of air, wind and other particularities of the local climate. However, similar changes of the subjacent surface in various natural-climatic zones lead in one case to favorable and in another to unfavorable climatic effects. Therefore for the correct assessment of the climate-forming significance of economic measures, leading to a change in the subjacent surface and consequently the local climate, it is necessary to consider these measures in close connection with the particularities of natural zones. (Ref 46, p. 54)

The chapter by Lyakhov[47], who was affiliated to the Institute of Aeroclimatology, explored atmospheric pollution and in doing so reflected on the impact of such pollution on health in addition to sources of both natural as well as economic pollution. Indeed, concerns over the possible negative impacts

of human activity, including atmospheric pollution, began to appear more frequently in the scientific literature during the late 1950s and early 1960s in tandem with general discussions concerning climate modification. A 1958 article by E.K. Fedorov[48] in the journal *Voprosy Filosofii* addressed the issue of the 'influence of humankind on meteorological processes' directly. Following a discussion of such things as artificial cloud formation and possibilities for climate regulation, Fedorov moved on to highlight the meteorological impact of artificial changes to the earth's surface through economic activity and in doing so made reference to the earlier work of Budyko and others in connection with the Stalin Plan (Ref 48, p. 143). In addition, he highlighted the scope for human activity to change both the chemical and electrical composition of the atmosphere before noting the potential for carbon dioxide to alter the balance of radiant energy in the atmosphere. Two interdisciplinary meetings devoted to the problem of climate transformation were held in Leningrad during April 1961 and June 1962 and organized by the GGO in collaboration with the Institute of Geography and the Institute of Applied Geophysics. These meetings covered a lot of ground and included papers devoted to historical climate change, heat exchange, and regional climate modification.[49,50] In concluding the second meeting in 1962 it was noted that more research was needed with respect to the 'general circulation of the atmosphere, natural and anthropogenic changes of climate, regional conditions for the transformation of climate and the influence on weather, and also research concerning the theoretical basis for artificially influencing clouds, fog and hail' (Ref 50, p. 187). The elevated interest in anthropogenic climate change in particular was captured effectively at this time in the work of Budyko and his colleagues. A 1962 paper by Budyko in the *Bulletin of the Academy of Sciences USSR*[51] reflected broadly on the issue of climate change and opened by noting the marked advances in scientific methods as well as meteorological data that had taken place from the mid-1950s thanks in part to initiatives such as the International Geophysical Year. The paper moved on to consider the artificial manipulation of climate via cloud-seeding and other means as well as highlighting the growing potential of human activity to influence climate regimes. More specifically Budyko noted that as a result of the development of technology and energy production capabilities a change of climate was more or less inevitable (Ref 51, p. 35). He also underlined the considerable interest directed towards the possibilities of influencing the ice cover in arctic regions; indeed, he published a paper devoted to this issue in the same year in the geographical literature.[52] In both papers, Budyko adopted a cautious stance:

> The question concerning the expediency of such measures [related to the destruction of ice cover] is very complex. One should have in mind that following the destruction of ice there would be a significant change in the regime of atmospheric circulation. (Ref 51, p. 36)

The general sentiment of this 1962 paper was repeated in a 1966 paper which Budyko published with colleagues from the GGO. This particular publication was subsequently made available in English in 1971.[53] All of these works demonstrated a keen awareness of both the growing influence of human activity on climate processes and the potential for such influence to result in both negative as well as positive consequences.

CONCLUSION

Interest in climate and the functioning of climate systems at a range of scales has a long history in Russia and simultaneously finds strong representation in Russian geographical thought and practice. During the post-1945 period understandings of global climate systems were furthered on both sides of the ideological divide and the exchange of ideas was facilitated by large-scale initiatives such as the International Geophysical Year (1957–1958), conference attendance and related activities. At the same time, the work of Soviet physical geographers has received limited explicit attention in English-language publications. This review has focussed on the decade or so following World War Two during which time understandings of climate systems and related work developed in a number of significant directions within physical geography as well as cognate areas. Such developments were framed by the shaping influence of state agendas during the early post-war period which ensured that geographical work moved strongly in the direction of supporting the advancement of the socialist economy. Work concerning the heat and water balance at the earth's surface emerged as a key focal point promising to assist in the purposeful transformation of nature and associated climate regimes over significant areas. This initiative drew strongly from Russia's long-standing tradition of climatological and broader natural science work in addition to the more recent collaborative work of geographers such as A.A. Grigor'ev and associated efforts to understand the complexities of natural physical systems operating at the earth's surface. The

practical application of such insight was particularly evident with respect to the activities of the Great Stalin Plan for the Transformation of Nature which prompted substantial scientific endeavor across the natural sciences in spite of its ultimate failure. The final part of the review noted the broadening of climate debate during the late 1950s and early 1960s within geographical circles characterized in part by an emerging awareness of the growing potential of human activity to influence climate regimes at a global level. Furthermore, while the ensuing debates embodied discussions over the need for greater knowledge about particular elements of the global climate system they also internalized an uncertainty over the nature of the links between human activity and climate. The work of Budyko and his colleagues at the GGO was most notable in this respect with the publication of a number of articles devoted to such matters.[51–53] In addition, the aforementioned work, in tandem with geographers such as Grigor'ev, concerning the earth's heat and water balance, provided a significant boost to later global understandings of climate change with its emphasis on the intimate linkages between different physical systems.

NOTES

[a] The chapter by Mott T Greene in Benson and Rozwadowski's edited volume on oceanography provides an interesting case study of the exchange of ideas between the Soviet climatologist M.I. Budyko and counterparts in the USA as part of their joint efforts to develop effective models of climate change during the late 1960s and early 1970s. See Further Reading for a full Ref .

[b] Gerasimov replaced A.A. Grigor'ev as Director of the Institute of Geography, Academy of Sciences USSR in 1951 and would remain in that position until 1985.

[c] P.E. Lydolph referred to it as the 'radiation index of aridity'.

[d] No 9 (137) 31 March 1950.

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