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Modelling the future: climate change research in Russia during the late Cold War and beyond, 1970s–2000

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Abstract
Climate models are what governments, experts and societies base their decisions on future climate action on. To show how different models were used to explain climatic changes and to project future climates before the emergence of a global consensus on the validity of general circulation models, this article focuses on the attempt of Soviet climatologists and their government to push for their climate model to be acknowledged by the international climate science community. It argues that Soviet climate sciences as well as their interpretations of the climate of the twenty-first century were products of the Cold War, and that the systematic lack of access to high-speed computers forced Soviet climatologists to use simpler climate reconstructions as analogues, with far-reaching consequences for climate sciences in post-Soviet Russia. By juxtaposing the history of Soviet climate modelling with the early history of the Intergovernmental Panel for Climate Change, which rejected the Soviet model, the article sheds light on the relationship of science and politics. The findings are based on archival and print material as well as on interviews.

Keywords Soviet Union · Russia · Paleoanalogues · IPCC · Cold War

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In a 1993 study on Soviet climate science, US scientists found that "the Soviets were among the leaders […] in the 1960s" in developing theoretical models of complex systems such as atmospheric circulation (Ellingson et al. 1993, p. I-4). In the early 1970s, US-Geographer Paul E. Lydolph (Lydolph, 1971, p. 637) concluded that climatology "has been developed to such a degree in the Soviet Union that it warrants a special study" and estimating that "perhaps half of the climatological literature published in the world" was "written by Soviet climatologists". Throughout the 1970s and 1980s, Soviet climatologists' achievements in general climatology, radiation, heat balance and agroclimatology made them attractive partners in international collaborations, such as the 1972 bilateral US-USSR agreement on scientific cooperation in environmental protection (Doose 2021). Following the collapse of the Soviet Union, however, their expertise did not keep pace

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with international climate science, and they somewhat disappeared from the global climate science scene, as witnessed by the rejection of their methodology in the first assessment report of the Intergovernmental Panel on Climate Change (IPCC) published in 1990. They only started to regain ground in the early 2000s.

Going beyond the valid argument of system collapse, this article explores how Russian climatology evolved in the aftermath of the regime change in 1991. It has previously been argued that Soviet climate scientists were marginalised for ideological reasons because their interpretations of the future climate contradicted western ones (Oldfield 2018). This article does not discount the close relationship between science and the state but shows that it exists in a wider context. Science has been political for centuries and is essential to political systems of modern states. With her concept of co-production of knowledge, Jasanoff (2004) argues that scientific knowledge embeds and is embedded in social practices, norms, discourses and institutions. Similarly, Livingstone (2003) regards the places in which science is conducted as crucial and calls for an exploration into the local contexts of knowledge production. Studies on the social embeddedness of climate models illustrate how models gain political authority, how they shape political decision-making and how they are shaped by politics (Hulme 2013; Hastrup 2013; Edwards 2010). Soviet models, including their conceptualization and application, were no different. This article argues that the seeming disappearance of Russian scientists and their models from the international climate scene stemmed not only from the heavy consequences of system collapse but also from the decades-long conditions created by the Cold War. These included insufficient access to technology, a low political priority given to climate change and academic compartmentalization. As a consequence, Soviet scientists developed an alternative climate model based on paleoclimate reconstruction which, in contrast to western projections based on the general circulation model (GCM), gave an overall optimistic forecast of the future climate of the Soviet Union. While this interpretation by the scientists was most likely not politically motivated, it still helped Soviet politicians to use this interpretation in order to minimise the problem of climate change and to further develop the economy based on natural resource depletion. Based on archival material from the Russian State Archive of Economy, the IPCC archive and published material and interviews with climatologists, this article contributes to an understanding of how social, economic and political factors shaped the development of climate science during the Cold War and beyond.

1 The struggles of Soviet climate modelling and the search for an alternative

Climate and weather sciences have a long tradition in Russia. Scientists had to understand climate in order to manage the vast territory, to cultivate the land and to build infrastructure. Recurring heavy droughts like in 1891 gave new incentives to invest in research on climate dynamics (Moon 2005). Later, the two world wars made meteorological knowledge strategically crucial for warfare in Russia, Europe and the USA (Edwards 2010). They promoted the advancement of a dense observation and data network, training of meteorologists and new instruments. Building on the large foundation of climatological studies undertaken by tsarist scientists, Soviet climatology has internationally become particularly known for the heat balance studies done by Mikhail Budyko. His 1956 monograph *Heat Balance at the Earth's Surface* was translated almost immediately into English by the US weather bureau and served as an important base to understand global climate

characteristics (Oldfield 2016). Drawing from this energy budget research, Soviet climatologists began in the 1960s to study global climate change and to build climate models despite the technological constraints. The following section will explore how the struggle for access to high-speed computers led to the creation of an alternative climate model that enabled Soviet scientist to remain part of an international climate change research environment, where GCMs increasingly gained dominant authority.

Computer capacities were scarce in the Soviet Union, for various reasons. The country's scientific achievements in fields that required computer infrastructure were strong in areas such as nuclear and space technology, but since the 1950s, it lagged significantly behind in technology compared to western countries. The centralised governmental control on "big science", the defence sector monopoly over computer access, the cloud of secrecy surrounding military computing and, later in the 1960s, interagency rivalry seriously harmed the development of Soviet computing (Gerovich, 2002). Moreover, in other countries, some of the most innovative work in computer hardware and software development had been done by individual entrepreneurs which did not exist as freely in the Soviet centralised economy (Graham, 1993). Until the end of the 1950s, the only civilian computer facility was at the Computation Centre of the Academy of Sciences, and even there, most computing time was used to perform military calculations (Malinovsky 1995; Gerovich 2002).

Soon after, various disciplines, among them Soviet meteorology, started to benefit from new computer technology. Research on weather and climate was funded and managed either by the Soviet hydrometeorological services (Gidromet) or by the relevant institutes of the Academy of Sciences. While the latter had better access to high-speed computers for research purposes, it was mainly scientists working for the former that were interested in climate change and its theories. Mikhail Budyko, for instance, was the director of the Main Geographical Observatory, which worked under the umbrella of Gidromet. The single institute of the Academy of Sciences that had the infrastructure and the theoretical know-how to build climate models was the Institute of Computational Mathematics led by mathematician Gury I. Marchuk (1925–2013). But his focus remained a very mathematical one as his teams researched methods of constructing models to improve numerical weather prediction. Climate interested them if its theory could help to extend weather prediction to seasons or at most a year or two, which resonated with the demand of the party state's policy on science that demanded research to be of use for the national economy and defence.

Similarly, the hydrometeorological services were obliged to direct their focus to weather prediction and less to climate models. As discussed by the Gidromet leadership in July 1977, long-range weather forecasting was considered "the central task of the Hydrometeorological Services". Its director Yury Izrael (1930–2014) even put long-range weather forecasting on the same priority level as nuclear technology, hoping that Gidromet would "tune in to long-term forecast, just as the country has reorganised itself during a certain period towards nuclear technology to what we now have and we need to raise the leading role of the Hydrometeorological Centre".[1] Comparing their activities to those of US peers who were working increasingly on climate change, he claimed that it was "easier to speak about climate and to make a forecast, than to forecast (the weather) for 2–3 weeks. For up to 200 years, one can predict many things".[2] While both long-range numerical weather forecasting and climate modelling were state funded and heavily supported in the USA and

[1] 1977, Yu. Izrael, Russian State Archive of Economics (hereafter RGAE) fond (f.). 8061, opis (op.). 9, delo (d.). 4033, list (l.). 12.

[2] Ibid., l. 14.

northern Europe, Gidromet, and, by extension, the Soviet government, focussed only on numerical weather forecasting. Some scholars have also argued that Gidromet minimised the importance of climate change in order to control dissemination of climate-related information and to maintain the institution's powerful status throughout the 1970s and 1980s (Sokolov et al. 2001). In this context, Budyko's studies on anthropogenic climate change took place in an intellectual niche, tolerated but neither viewed nor treated as high priority.

Atmospheric models were eventually developed in the Soviet Union at various institutions of the Academy of Sciences. The earliest was built by Marchuk at the Institute of Mathematics, who used numerical modelling of atmospheric processes for numerical weather forecasting. From 1973 on, he made mathematic calculations of atmospheric-ocean dynamics along theoretical lines very similar to the coupled atmospheric-ocean circulation model of Kirk Bryan and Suyuki Manabe at the US Geophysical Fluid Dynamics Laboratory (Marchuk et al., 1984). But in contrast to Bryan and Manabe, Marchuk could not test his results immediately on computers. The research for this theoretical model was later tested on the supercomputer CRAY-1 at the European Centre for Medium-Range Weather Forecasts in Reading and at the supercomputer of the International Institute of Applied Systems Analysis (IIASA). Between 1981 and 1984, Marchuk then initiated "Sections" (Rus.: razrezy), a research programme studying oceanic influences on short-period climate oscillations (Ellingson et. al, 1993, xvi). Despite the scale and expense of the project, his interest was advancing mathematical calculations of seasonal and annual weather changes, rather than anthropogenic climate change.

Throughout the 1980s, other institutions began to develop and apply climate models with varying capacities and applicability (Ellingson et al., 1993). For instance, the Institute of Oceanography and the Institute of Atmospheric Physics (IFA) studied climate change, but did not develop or run numerical models. Of particular significance were the modelling efforts of Vladimir Alexandrov at the Computer Centre of the Academy of Sciences, part of the Nuclear Winter Project run by Soviet Nikita Moiseev. While this project advanced Soviet studies of anthropogenic environmental impact and redefined understanding of human-nature relationships (Rindzeviciute 2016), it did not advance Soviet numerical climate modelling. This was primarily because instead of building a model themselves, Alexandrov and his team copied the Mintz-Arakawa model from the University of California (Rindzeviciute 2016). Moreover, for Moiseev's Global Biosphere Model or his global development model (Aleksandrov et al. 1983; Rindzeviciute 2020), scientists were interested in climate scenarios mainly as certain aspects of global changes in the biosphere, demography or the economy and not in anthropogenic climate change per se. Although the Nuclear Winter Project advanced computer-based modelling as a branch of research in the Soviet Union, this did not translate into better climate models.

The lack of computer capacity was certainly a major reason for the slow development in Soviet climate modelling. Limited budgets pushed the Soviet government to prioritise fast computers for research directly linked to military purposes. Climate change research was not in that category. After a 6-month research stay in the USA in 1978 within the framework of the 1972 US-USSR Agreement on Environmental Protection, Valentin Meleshko from the GGO concluded that "the abilities of our serial computers, which we use for similar research, are 10–100 times lower [than those of the US]. This is one of the biggest problems that prevents the development in the field of climate research with hydrodynamic

methods in our country".[3] Apart from the joint work on the Nuclear Winter Project, climate modelling disappeared from the bilateral US-USSR collaboration on climate change when it transpired that no exchange was possible. Moreover, the Soviet Union struggled with the preconditions for technological innovations: the need for innovation, skills and budget (Kalmanek 2012; Marburger 2011). The first precondition drives the other two, and the Soviet science system, being non-receptive to innovation, entered the supercomputing race rather late, in 1948. For a while, it remained unclear whether analogue or digital computers should be prioritised. These internal disagreements, coupled with systemic centralised decision-making, slowed down the development of digital computing (Gerovich 2002). When in the late 1950s, its importance was finally understood; the west was already so far ahead that the Soviet government decided to simply buy any necessary machines and hardware. Technology, however, requires constant sustaining and improvement — once acquired, it does not develop on its own. In 1968, the Soviet supercomputer BESM-6 was already 90 times slower than the CDC supercomputer in the USA (0.418 vs. 36 MFLOPS). Gidromet only bought its first supercomputer from the USA, a CDC-7600 (Cray Supercomputer), in 1985.

The Soviets also lacked the computation and programming knowledge infrastructure which was crucial to the development of climate modelling (Edwards 2010). The laboratories Meleshko visited in the USA usually employed between five and ten experts in "computational aspects of the problem, as well as in basic sections of atmospheric and oceanic physics: radiation, boundary layer, energetic atmosphere and its moisture circulation". In addition, "most team members were very skilled in programming".[4] The Soviets only had teams of between one and three, scattered over various institutions and disconnected, which, Meleshko reported, made complex problem solving impossible. For instance, physicist Andrey Monin (1921–2007), Director of the Institute of Oceanography, attempted to build a coupled atmosphere–ocean model like that built by Marchuk and his team but had too few mathematicians to complete it.[5] In the early 1970s, Soviet modeller Valentin Dymnikov wanted the IFA to become the National Centre for Atmospheric Research in the USSR, which would have required high-speed computers and mathematicians. The director of the IFA, Aleksandr Obukhov (1918–1989), turned the proposal down, on the basis that the scale of the project was beyond his capacity, and that even as a physicist, he did not adequately understand the science.[6] Instead, the institute's focus remained on fundamental physical processes. These initiatives show that interest to advance climate modelling was at least partially there, but that the institutions lacked the proper knowledge infrastructure to implement the ideas. Moreover, as Meleshko pointed out, collaboration between these institutes was not common, which also limited productivity. With the exception of Vladimir Aleksandrov, a physicist who collaborated closely with the IFA to develop his model, the disciplinary void between mathematicians or programmers and physicists presented a high barrier.[7]

[3] 1978, V. Meleshko, RGAE f. 8061, op. 11, d. 550, l. 167–8.
[4] Ibid., l. 174.
[5] Interview with V. Dymnikov, July 2018.
[6] Ibid.
[7] Interview with G. Stenchikov, February 2021.

1.1 Paleoclimate models as an alternative to computer modelling

While Soviet science struggled to keep up with western computer technology, Soviet climatologists were considered important theoretical modelling experts. Geophysicist Mikhail Budyko (1921–2000), for instance, was an internationally renowned expert on the Earth's heat budget and had decades-long scientific standing both domestically and abroad (Oldfield 2016). However, the concern about climate change since the 1970s shifted the interest to predictions for which powerful computers were needed and which were not accessible to Soviet climatologists. Looking for an alternative to circumvent the gap, Budyko and his team relied on paleoanalogues, a paleoclimatological approach, which uses knowledge from the deep geological past to make climate predictions. In the next section, I refer to paleoanalogues solely as attempts to use past climates as analogue for climates in the future.

Budyko's paleoanalogue model aimed to predict the possible future evolution of the twentieth-century climate and vegetation by studying similar climatic conditions of a past geological era. Having studied various eras, Budyko and his colleagues finally focused on the early-mid Pliocene (5.3 to 3.6 mm years ago), previously explored via lithogenous (marine sediments), geobotanical and zoological proxies. In the USSR, the groundwork on paleoclimates, or ancient climates, had largely been done by geologist Vasiliy Sinitsyn (1912–1977) (Sinitsyn, 1965, 1966, 1967). With the help of Sinitsyn's paleoclimatic maps, Budyko, his PhD student Irena Borzenkova and palaeontologist Vsevolod Zubakov (Borzenkova and Zubakov, 1984) pioneered climate studies of the mid-Pliocene with climate change in mind and concluded that the climatic situation of the coming centuries would be a repetition of the thermal optima of the Holocene, Pleistocene and Pliocene (Budyko, Izrael, 1987; Budyko, 1988, 1989, 1991). This meant that that the temperatures in high latitudes would increase 2.5–3 times faster than in low latitudes. Zubakov and Borzenkova (1988) determined that the future climate would be more humid in most regions of the world, as in the Pliocene. A considerable temperature increase was also expected in middle and high latitudes which, along with direct photosynthesis effects, would enhance plant and crop productivity (Budyko, Izrael, 1987; Budyko, Sedunov, 1990). While they regarded this climate as initially beneficial for the Soviet Union, they also warned of a much stronger warming in the more distant future (Budyko, Sedunov, 1990). Their understanding of climate change pointed to a cyclical nature and to uniformitarianism, according to which natural processes repeat themselves in past and present.

The idea of paleoanalogues was not new. Charles Lyell had introduced a geological analogue approach in his *Principles of Geology* in 1830, suggesting strong links and regularities between the climates of different epochs. This type of uniformitarianism has been criticised because it ignores the uniqueness of the present and the future climate. Roger Revelle and Hans Suess, for example, argued that "[H]uman beings are now carrying out a large geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future" (Revelle and Suess, 1957, 19). A few years later, in 1964, Edward Lorenz pointed out that the "atmosphere is essentially a one-shot experiment" (Lorenz 1964, 2). Similarly, the ideas to learn from paleoclimatic records (Kellogg 1977) or to use paleoanalogues to predict the future, advocated mainly by Budyko, were criticized (Schneider 1984; Crowley 1990), especially over data reliability. Stephen Schneider emphasised that the equilibrium calculations of past climates ignore the possibility of major transient effects (Schneider 1984). Later, Thomas J. Crowley

argued that the Pleistocene interglacials may not have been significantly warmer than the present, and that these studies overlooked the possibility of the effects on climate of different geographies. Furthermore, he noted that the combination of warm atmospheres with polar ice sheets is very new, providing for conditions markedly different from past periods. As it may take thousands of years for the deep oceans and continental ice sheets to come into balance with a much warmer atmosphere, the difference between this ideal equilibrium and the actual climate is so great that no past climate will ever be a satisfactory analogue for the future (Crowley 1990). Like Revelle, Suess and Lorenz, Crowley urged the warming to be seen as a "unique climate realization in earth history" (Crowley, 1990, p. 1290).

The main issue with Budyko's model was that instead of focusing on mankind's agency and using geology as an empirical tool to validate numerical models (Oreskes et al., 1994), he and his team saw in it a script for the future. Budyko's team acknowledged the effects on the climate of fossil fuel combustion, but for the sake of their model and to create an alternative to numerical prediction models, they equated it with the non-anthropogenic forcing factors in the Pliocene, when humans did not yet exist. By disregarding the chaotic behaviour of the general earth system, they believed earth history could repeat itself. They equated the nature and origin of contemporary CO2 with its geologically ancient origins, thus at least partly deleting the human factor from their equations.

Access to high-speed computers might have negated the need to eliminate anthropogenic factors from their model. In an interview with science historian Spencer Weart, Budyko pointed out that the paleoanalogue method was "the approach of poor people, […] the only way to do something with practically very little expense. […] The great majority – including me – believed that computer models in comparatively short time can solve all problems" (Weart, 1990). Similarly, his former colleague Konstantin Vinnikov remembered how Budyko knew he would not see the complex climate models running on high-speed computers in Russia before his death.[8] Furthermore, he said, a simple model that could be used in parallel with GCMs provided the opportunity to stay connected with his western colleagues, to exchange intellectually, to be able to travel abroad again and to thus benefit financially from the per diem salaries.[9]

However, what became most crucial for him, for his international career and for the reputation of Soviet climate scientists, was the extreme view on climate change that he drew from his model results. The overall optimistic outlook on the consequences of anthropogenic climate change led Budyko to make increasingly bold statements concerning alterations in fossil fuel consumption. At a conference in Hamburg in 1989, for example, he allegedly called any attempt to reduce the anthropogenic impact on climate a "crime against humanity".[10] It remains unclear where this radicalisation came from and to what extent it was connected to government demands or his own scientific convictions. But his model and interpretations were Cold War products: the model was developed from a lack of access to high-speed computers, and the interpretations reflected the Soviet ideology that human progress justified resource depletion. Rosol (2015) sees paleoanalogues as a "blatant farce of denialism" (p. 45). While this is not entirely true for Budyko's work, which acknowledges anthropogenic CO2 as a factor for climatic changes, his method and

[8] Interview with Konstantin Vinnikov, February 2019.

[9] Ibid. February 2021.

[10] IPCC archive, letter Alan Hecht to IPCC consortium, May 1989 (no date).

data interpretation nonetheless provided unintentionally a foundation for subsequent climate denialism in Russia.

This section has shown that availability of technology in weather and climate models is a question not only of funding but also of staff education and of a knowledge infrastructure. Archival sources provide little evidence to show how far Budyko's model penetrated Soviet politics. His optimistic forecast resonated with the idea of economic progress and the agricultural superiority of the Soviet Union, which may explain why his model and its results had gained acceptance in the USSR and remained generally unchallenged. It gave scientists and the government alike more leverage to interpret the changes as beneficial for Soviet territory. How this different approach became increasingly problematic also on the international political level will be the focus of the following section.

2 The IPCC and the politicisation of the Soviet paleoanalogues

Until the IPCC's inception in 1988, the debate about the usefulness of the Soviet analogue approach remained at the scientific level. But the IPCC was to become a science-policy body charged with giving univocal advice to facilitate policy decision-making, and, for this, consensus was required in both methodology and interpretations of data. Moreover, the focus would remain on anthropogenic influences on climatic change. The debates among contributors to the First IPCC Assessment Report show that considerable attention was given to the issue, and that scientific, rather than ideological reasons played the decisive role in rejecting the Soviet paleoanalogue method. Still, the debates and subsequent reduction of Soviet scientific influence on the newly formed science-policy body illustrate how the old bipolar world stopped shaping environmental knowledge in the new multilateral setting of the IPCC.

2.1 The USSR's role in the formation of the IPCC

It is known that the US government pressurised the IPCC to emphasise the need for more research before officially advocating any action on climate change (Agrawala 1998). In particular, powerful fuel lobbies supported by the Republican administration strongly opposed any measures against climate change. The US government was the biggest financial patron of the UN system, giving the USA significant weight in the decision-making processes of the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP). Moreover, various US agencies and research institutions disagreed heavily on the need for a policy response, providing grounds to create a science-policy body to stall for time (Agrawala, 1998). To gain authority and to attract credible experts, three working groups (WG) were created, each chaired by a representative from strategically important countries. WG I on science was chaired by John Houghton, general director of the Meteorological Office in the UK, WG II on impacts was chaired by Yuri Izrael and WG III on response strategies was chaired by Frederick Bernthal, the US Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs. The latter group was widely criticised for advocating weak measures, such as targets for reductions in greenhouse gases (Mackenzie 1990).

Although the allocation of the WG chairs was decided at the first plenary session of the IPCC in November 1988 by consensus, the Soviet delegation was disenchanted with the process that evolved. Recognising the potential of strict climate policies as leverage against

the coal mining sector in the UK, Margaret Thatcher's British government was early advocators of more research into climate change — domestically by founding the Hadley Centre for Climate Prediction and internationally by pushing for the WG I chair. At the first plenary session of the IPCC in November 1988, the UK delegation arrived well prepared with a concept for WG I and was univocally accepted as its chair.[11] Although the Soviet delegation at the time did not oppose the move, they later appeared to have felt "left out of the process".[12] At a WG II meeting held in Nalchik in February 1990, Izrael openly criticised the WG I report, arguing "it was not written by the best scientists in the world" and hinting that Soviet scientists in WG I were not given prominent author positions.[13] Izrael also protested against the WG I chair decision by still including references in his group report to analogue-based scenarios, although this was explicitly not intended in order to keep the structure of the report (Bolin 2007).

Izrael's perception of having been sidelined by the international community stood in stark contrast to the Soviet Union's previous engagement in climate research collaboration with scientists from the USA in the framework of the 1972 US-USSR Agreement on Environmental Protection (Doose 2021). In order to create a synthesis of the collaborative research of the previous 15 years, US and Soviet scientists were asked in 1987 by US President Reagan and Soviet Leader Gorbachev to publish a joint report on their climate change research (MacCracken et al. 1990). The book was published in the autumn of 1990, at the same time as the First IPCC Assessment Report. There were debates among the editing team around the question of paleoanalogues but were settled relatively smoothly in the bilateral setting (Doose 2021). Paleoanalogues were included; only the US scientists made sure that Soviet results would be phrased with great caution. As such, the book's introduction states that "past intervals of warm climate, may provide important insights into the characteristics of the future climate", but that "these past periods differ from the unique conditions that we project for the future" (MacCracken et al. 1990). Driven by the overwhelming need for climate data, both sides accepted (at least on paper) one another's approaches to calculating climatic changes.

2.2 Deciding upon the already decided: the IPCC Bath meeting

By contrast, the Soviet analogue method was heavily debated and eventually rejected from the first IPCC report. The compromise in wording found in the US-USSR report was now impossible for the IPCC report because more parties were involved. In addition, the inclusion of the paleoanalogues would have jeopardised the entire idea of a science-policy tool that was to unequivocally inform governments and societies. As Houghton explained, "[i]t would be of no use to policymakers if we offered them two quite distinct predictions without guidance on which we believed was most credible".[14] In order to avoid disagreement going forward, the WG I chair, John Houghton, decided that Mikhail Budyko would not be a lead author within WG I but would only be a contributing author to Sect. 5 (Equilibrium Climate Change).[15] Considering that Budyko had been regarded worldwide as one of the

[11] Interview with John Zillman, (First Vice-President of the WMO 1987–1995), April 8, 2021.
[12] IPCC archive, Telex from J. Houghton to Y. Izrael, March 1990 (no date).
[13] Ibid.
[14] IPCC archive, letter from J. Houghton to Y. Izrael, 1989 (no date).
[15] Ibid.

leading climate scientists for many decades, this must have been a deep disappointment for him. But most of all, it was a significant marker for the dwindling importance of Soviet climate modelling.

However, Budyko and Izrael tried to fight against their exclusion. In his role as a contributing author in Sect. 5, which in its original outline included predictions based only on simulations with GCMs, Budyko asked for the paleoanalogue technique to be included. In response, Houghton organised a meeting with some of the contributing authors of several sections, including Budyko's, in Bath in November 1989. In his invitation letter, Houghton explained "that this section should also deal with the paleoanalogue technique of climate forecasting, with a discussion of uncertainties in the techniques and regarding which technique is most likely to give the best indications of future climate change".[16] Pointing to the relevance of the discussion's outcome, he announced that "this is not just an academic issue; the forecasts from the two techniques are different and may have different policy implications […]", signalling once more the IPCC's aim of a univocal result.[17]

At the Bath meeting, the discussions centred on the quality of the paleoclimatic data for the three warm epochs (Holocene maximum, Eemian, Pliocene maximum) and their comparabilities considering the differences in climate forcing (e.g. greenhouse gases, orbital variations) and boundary conditions (e.g. ice coverage, topography).[18] Apart from the three Soviet scientists at the meeting, Mikhail Budyko, Andrey Velichko and Konstantin Vinnikov, all other scientists, from the USA and the UK, questioned the quality and quantity of data. They also objected to the uncritical use of reconstructed climates as analogues of changes in ice cover and changes in orbital parameters. The meeting resolved with the decision to not include the paleoanalogues as forecasts, and that much more work was needed to acquire paleoclimate proxy data and data on past boundary factors.[19]

However, the meeting did not close the debate. A number of correspondences followed between Izrael, Houghton and the coordinator of the IPCC Technical Support Unit at the UK Meteorological Office, Geoffrey Jenkins. In most letters, Izrael pointed to the IPCCs initial statement according to which all existing methods and scientists would be included, while Houghton kept falling back on the concluding decision taken at the Bath meeting. At several subsequent WG I meetings at which Budyko himself was no longer present, his Soviet colleagues advocated for the full inclusion of the paleoanalogues in the assessment report. For instance, at the Edinburgh meeting in February 1990, Valentin Meleshko and Konstantin Vinnikov tried to convince the other scientists of Budyko's method. In the plenary session, the discussion on paleoanalogues resurfaced, and Thomas Wigley, Bert Bolin and others openly opposed the method for forecasting.[20] Nevertheless, according to the official Soviet report, Vinnikov and Meleshko distributed leaflets prepared by Budyko with comments on the paleoanalogues for the subchapter and used the coffee breaks to try and convince other delegates — but to no avail.[21] Even at the final WG I conference in Windsor in May 1990, when the final draft of the assessment report was presented, Meleshko tried again to get the paleoanalogues involved. In the end, the paleoanalogues are explained in a subchapter of the IPCC report written by Budyko, but the policymaker summary still stated

[16] IPCC WG1, letter from J. Houghton to many, 22 August 1989.
[17] Ibid.
[18] IPCC WG1, A.B. Pittock, trip report, 7 December 1989.
[19] IPCC archive, WG 1, Report, J. Houghton, 21 November 1989.
[20] 1990, Meleshko and Vinnikov, RGAE f. 8061, op. 11, d. 3969, l. 34.
[21] Ibid.

that the report "cannot advocate paleo-climates as predictions of regional climate change due to future increases in greenhouse gases" (Houghton et al. 1990, p. xxv).

In addition to the scientific objections to the method, there were political and strategical reasons for such strong reactions that shed light on how the authors and organisers of the first IPCC report sought to influence future policy decisions. It is important to note that the exclusion of the Soviet method was not aimed at the Soviet Union or Soviet scientists. Rather, it seemed like a rejection of anyone advocating a no-action climate policy as the following exchange will show. Prior to the Bath meeting, in June 1989, geographer and lead WG II Author Martin Parry from the University of Birmingham had informed the IPCC coordinators of his newest findings in his research at IIASA, which looked at the impacts of climatic variations. "I am facing [sic] you in confidence", he wrote to his colleagues at the IPCC 'diagrams of estimated changes in potential wheat productivity for USA and USSR under Budyko's "paleoclimatic scenarios". Note the large increase in potential for the USSR, in contrast with the USA. If this material is included in the WG II's report, there are serious implications for policy (especially for the "do nothing" strategy) […]. This issue is getting very messy; and it is shot through with politics'.[22] Later, shortly before the publication of the first Assessment Report, he repeated his urgent plea. After Budyko had failed to get the paleo approach included in WG I as a valid forecast method, he had tried to use its results for the impact studies in WGII report, which raised serious concern about the consistency of the entire report. Parry argued again that their "inclusion is not appropriate", and that the IPCC "must take seriously the risk that those who advocate no action on greenhouse gases would be tempted to latch on to the paleo estimates as substance for the argument".[23]The IPCC assessment clearly aimed for a univocal guidance for policy action on projected climate change. Their report was not to be construed as advocating inaction, regardless of the tenacity of Soviet authors. It seems, therefore, that although the rejection of the paleoanalogues was based on scientific objections, it was also in part politically motivated.

However, it is less clear whether the persistence of the Soviet scientists in pushing for the model was driven by politics, as Bert Bolin suggested (Skodvin 2000). The political weight within Soviet science should certainly not be underestimated, but Budyko, then already 70 years old, had nothing much to fear. Furthermore, the Cold War was at an end, and Gorbachev's perestroika policies had eased the political pressures on scientists. Budyko in fact advocated the use of paleoanalogues beyond the fall of the Soviet Union, well into the 1990s. Not only was he scientifically convinced of their use in understanding climate change, but his insistence can also partly be explained by a fear of losing ground in a field where Soviet scientists had once competed on equal terms with their western colleagues. Dropping the paleoanalogues from the IPCC, the newly founded global science-policy body, in favour of GCMs, was tantamount to losing power within the world climate community and on climate change debates in general, which were only just beginning to receive broad political attention. At the same time, Yuri Izrael, who had lost political support domestically over the Chernobyl disaster, tried to reposition himself politically through the climate change issue by strongly advocating the Soviet method. Both the academic and political factors may have been mutually reinforcing, hence the persistence. The following section will explore how the Cold War conditions continued to shape the Russian

[22] IPCC WGI, M. Parry to A. Apling and G. Jenkins, 19 June 1989.

[23] IPCC WGI, M. Parry to B. Bolin and others, 24 April 1990.

climate community after the dissolution of the USSR and how the paleoanalogues paved the way for today's climate scepticism in Russia.

3 The rise of paleoclimatology and post-Soviet climate science in Russia

Using paleoanalogues for long-term predictions had failed to convince the mainstream climate community. Paleoclimatology, on the other hand, the science that aimed at understanding past climatic phenomena, gained internationally unprecedented attention in the course of the 1990s as a validator of climate models. While it was not the debates about Budyko's paleo models alone that increased focus on the empirical climate approach, they may nonetheless have helped to sharpen the view on the use of paleo data in general. By the end of the 1980s, there was a large global paleoclimatology community whose members complained that the deep past is not always acknowledged by the climate modelling community, which generally favours instrumental data and is unwilling to go beyond historical records of the last 2000 years.[24] Indeed, it took the paleo-community another 20 years until the Pliocene was finally included in the Fourth IPCC Assessment Report (2007) as a representation of "an accessible example of a world that is similar in many respects to what models estimate could be the Earth of the late twenty-first century" (Jansen et al. 2007, pp. 440–442). By 2009, the Pliocene had "entered the political mainstream of climate change science" (Haywood et al., 2008, p. 6), and paleoclimatologists continued to argue for the evaluation of climate models in paleoclimatological experiments (Haywood et al. 2011). After the fall of the Soviet Union, Russian climatology benefited from this trend and remained very strong in paleoclimatology, but it recovered slowly in climate modelling. The move from a centralised science system to a more decentralised one, associated budget cuts, technological backwardness in computer capacities, and also the order of political priorities in Russia (Graham and Dezhina 2008) remain very important factors. But the story of the paleoanalogues also shows that the inability of Soviet and subsequently Russian climatology to keep up with scientific developments abroad had their roots in the Cold War. By looking at the evolution of post-Soviet climatology and their associated debates, this last section will explore how the paleoanalogue approach shaped and impacted contemporary Russian climatology.

Despite the rising integration of results from paleoclimatology into the IPCC assessment reports, Russian climatologists struggled to continue their research and to advance in modelling, as a consequence of the dissolution of the Soviet Union. Between the years 1992 and 1998 in particular, very little was published by Russian climatologists and cognate scientists, hinting at the socio-economic struggles of post-Soviet academia (Graham and Dezhina 2008). At first glance, paleoclimatology requires less technology and financial infrastructure than numerical climate modelling, but, with the rise of the discipline, computers and sophisticated infrastructure for collecting new proxy material from the deep sea, for instance, became vital. While Budyko's models were thought-provoking, they were also considered rather simple and based on too few data to be acceptable. Moreover he, like the majority of other scientists at the time, lacked a global sea surface temperature field to run an atmospheric climate model. In 1988, US Geological Service (USGS) and NASA

[24] Correspondence with H. Dowsett, project leader of PRISM, January 2020.

scientists Richard Poore and David Rind, who had heard Budyko's presentation at a conference in the US in 1987, picked up on that gap between theory and data in Budyko's work.[25] The USGS created one of the largest Pliocene projects called PRISM (Pliocene Research, Interpretation and Synoptic Mapping) to reconstruct global sea surface temperature at a specific time in the Pliocene, in order to then run a climate model (Robinson, 2011). The scope of the project, which is partly based on Budyko's idea and data, emphasised and contrasted with the lack of financial resources and infrastructure the Russian community faced.

Nevertheless, Russian work on paleoclimatology advanced, albeit on a much more modest scale. This was chiefly through the Institute of Geography, as well as various laboratories of paleophytology and paleobiology of the Academy of Sciences. Moreover, research continued at the Department for Climate Change at the State Hydrological Institute, which Budyko had founded in 1975 and headed until his death in 2001. Here, Irena Borzenkova and her colleagues continued their research on past climates using the proxy data already collected in the preceding decades. Empirical and semiempirical studies for a broad spectrum of time scales and paleo reconstructions have kept their role in Russian climate change studies and started to expand with new financial means in the early 2000s, making it possible to create new drilling sites in such locations as Lake Baikal, but also through data from the Vostok station in Antarctica (Mokhov 2009). In these later works, the emphasis has not been on using past periods as analogues but rather as a useful tool to understand climate phenomena.

The Russian modelling community struggled much more, owing to their dependency on powerful technology. In the late 1990s, research institutions[26] began to purchase more high-speed computers for their work on coupled atmosphere–ocean models. The IFA RAN only developed an ocean general circulation model in 2008 but failed again to develop a coupled model (Muryshev et al. 2009). To date, Roshydromet has better and stronger computers than other institutions, since their funding situation benefits from their status as a quasi-ministry of military interest. They were able to purchase a modern supercomputer in 1996, though this was largely to conduct numerical weather predictions (Bedritskii et. al. 2017). In contrast, the GGO, also run by Roshydromet, struggled throughout the 1990s to acquire the much-needed technology. During the worst years, 1992 to 1994, most scientists went unpaid, having to work in the private sector and coming to the GGO only once a week, to stay at least somewhat connected with the science.[27] Under these circumstances, Valentin Meleshko further refined his 1983 atmosphere model which was included in the Atmospheric Model Intercomparison Project (AMIP) in 1996 (an effort to improve models by comparing them). But in order to ensure comparability, the next cycle of AMIP required all participants to have strong computer capacities, which the GGO lacked. The observatory, the historical home of Russian climatology, was never able to build a coupled atmosphere–ocean model and so had to drop out of international level climate modelling. Its research focused instead on applied seasonal weather forecasting and on regional climate models (Shkolnik et. al. 2007). Its sponsor, Roshydromet, has showed marginal interest in climate change science up until the late 2000s. That changed only in 2008. Since then, it has produced regular climate change reports for the Russian government, an effect which

[25] Correspondence with H. Dowsett.

[26] The GGO, the Institute of Numerical Mathematics (IVM RAN), the Institute of Atmospheric Physics (IFA RAN) and Roshydromet, the successor organisation of the Soviet Hydrometeorological Services.

[27] Personal correspondence with Evgeny Rozanov, former GGO scientist, now World Radiation Center/ Davos, November 2020.

may be because some of its scientists received the joint Nobel Peace Prize as IPCC contributing authors in 2007. However, that still did not result in more high-speed computers for the GGO.

The institutes of the Academy of Sciences played a more significant role. As such, the Institute of Numerical Mathematics remains until this day the only institution in Russia that possesses the necessary computer power, infrastructure and skilled staff to develop and run numerical climate models. Here, the first Russian atmosphere–ocean coupled general circulation model was built in 2000 by the students of the Marchuk school, among them Evgeniy Volodin and Valentin Dymnikov (Volodin and Dianskii, 2002; Dymnikov et al. 2002). By 2002, they were finally able to make climate projections on their own. As a focal point in Russia for theoretical and fundamental mathematical research with a wide range of applications (not least military), their access to computer technology was by far more advanced, the staff better skilled and more funding available than at the institutions financed by Roshydromet.

This greater ability to project climate change secured a renewed participation of Russian climatologists in important discussions in the subsequent IPCC reports. At the same time, however, the division between advocates of anthropogenic climate change and its persisting opponents sharpened significantly. With the disappearance of Soviet censorship towards the end of the 1980s scientists felt freer to express their opinions and beliefs, including in newspapers and in TV interviews. Geophysicist Kirill Kondrat'ev (1920–2006) for instance promoted the idea of natural oscillations of the climate system (Kondrat'ev, 1987) and later criticised Budyko for taking a western position in order to advance his career (Kondrat'ev, 2002). Evgeny Borisenkov (1924–2005), the former director of the GGO, argued for solar activity as the main driver of climate change (Borisenkov, 1988), an idea that excited the solar science community at the time. Both stood in strong conflict with Budyko and are said to have rarely been seen in the same room together (North 2020). Others suggested additional natural external forcing such as the influence of the planets or changes in the Earth's orbital parameters (Meleshko et al., 2008). As divisive as these sceptical opinions may have seemed by becoming more vocal and visible after 1991, they all presented a continuity of the Russian tradition of scientific naturalism (Dronin and Bychkova, 2018), to which Budyko's model, although not his overall views on anthropogenic climate change, also belonged. Scientific naturalists explore nature as an objective entity and accept only natural causes (Larvor 2015). One of the drivers for this approach in the Soviet Union was the Institute of Geography of the Academy of Sciences, which was not involved in climate modelling but which had laid important foundations for scientific understanding of anthropogenic environmental changes in the Soviet Union. Both former directors of the Institute of Geography Andrey Grigor'ev (1883–1968) and Innokenti Gerasimov (1905–1985) developed the concepts of "Superprocess" (Grigor'ev 1946) and "Constructive Geography" (Gerasimov 1966), ideas about the applied function of geography as a discipline in the Soviet Union. In line with the Soviet discourse positing humans as separate from nature and thereby capable of conquering it, they also believed that humans could alter nature. But according to their concepts, which determined Soviet understandings of human-nature relationships among earth scientists, this was only possible on a local or regional scale, and it was temporally limited. Consequently, in Dronin's and Bychkova's interviewee samples as well as in publications (Dinevich et al. 2013; Kapica, 2010; Abdusamatov 2019; Moldanov 1998), a significant part of the older generation of Russian environmental scientists attributes the ozone hole depletion and climate change to endogen, non-human forces, a position not uncommon for empirically working Earth scientists (Lahsen 2005, 2013). This also explains the rejection by a range of geographers and other scientists in Russia of

the concept of the "Anthropocene" as a particular era of human impact on the Earth system (Bogdanov 2019).

In contrast to these few, but politically well-supported sceptics, Budyko was among the very few to follow Vladimir Vernadsky's (1863–1945) ideas on the noosphere and to corroborate the human impact on the atmosphere. At the same time, the model Budyko proposed resonated with the naturalist tradition. Budyko's idea to consider the amount of CO2 from the Pliocene and to draw analogues marginalised the very idea of an Anthropocene uniqueness against a simple continuation of the Holocene. His model, not his overall approach to climate change, thus rejected the merging of the natural and the anthropogenic world, which makes it part of the natural development of the long-standing Russian scientific naturalist tradition. While Budyko's overall views and findings form a strong exception to the bulk of the Soviet and Russian scientific community and cannot be held accountable for rising climate scepticism after 1991, his analogue model stood in this very same tradition by removing humans out from the equation.

4 Conclusion

This article sets out to explore why Soviet and Russian climate scientists, renowned for their work during the 1960s and 1970s, lost their high status within the international climate science community in the aftermath following the regime collapse of the Soviet Union. It argued that research in Soviet climatology was largely shaped by Cold War conditions and Soviet science policy, which prioritised military research and neglected many other fields, including climatology. Consequently, scientists often had to improvise to circumvent the dearth of technology, but could still not keep up with the rapid pace of science, as illustrated by Budyko's climate model. The model's optimistic forecasts resonated with the state's aims of economic progress and thus gained wide domestic acceptance. On the international level, it enabled Soviet climatologists throughout the 1980s to stay connected with their western colleagues and to create a platform from which to maintain academic exchange on anthropogenic climate change, a topic that became increasingly important. However, the paleo-analogue model that was somewhat endured for the US-USSR cooperation on climate change was now fully rejected by the emerging global climate science community and the IPCC. Scientists now openly doubted the robustness and reliability of this approach and excluded it from IPCC reports as a valid method to predict climate change. The Soviet Union lost its privileged position on the international climate scene, and its climatologists almost disappeared from it until Russia was again able to produce climate models adequate enough to be considered. Tracing this history of Soviet climate research, the article does not only shed light on the continuities between the Soviet and the post-Soviet period. It also documents the increasingly high entry barriers to climate research, which are determined by political, social and economic factors. These determine the availability of technology and human infrastructure needed to advance climate research and determine the '"owner" of the knowledge about the (climate) problem' (Edwards 2010, p. 171). While the Soviet Union was once one of these "owners" and producers of knowledge on climate change for many decades, its successor state Russia ceased to be among the main players after 1991. This was not only due to the heavy consequences of the collapse of the Soviet science apparatus, which substantially slowed down the recovery of Russian climatology, neither was it just because they were sidelined by their western colleagues for ideological reasons. More significantly, Soviet Cold War science policy had

over many decades increasingly stripped Soviet climatologists of the possibility to acquire new knowledge that connected them to the global scientific community.

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References

Abdusamatov K (2019) Solnce diktuet klimat zemli [The Sun dictates the earth's climate] Logos, Saint Petersburg

Agrawala S (1998) Context and early origins of the Intergovernmental Panel on Climate Change. Clim Change 39:605–620

Aleksandrov V et al (1983) Global'naia model' sistemy okean-atmosfera i issledovanie ee chuvstvitel'nosti k izmeneniiu kontsentratsii CO2 [A global model of the ocean-atmosphere system and the study of its sensitivity to changes in CO2 concentration] Izvestiia AN SSSR. Fizika Atmosfery i Okeana 19(5):451–458

Bedritskii A et al (2017) Roshydromet supercomputer technologies for numerical weather prediction. Russ Meteorol Hydrol 42(7):425–434

Bogdanov N (2019) K voprosu o tselesoobraznosti ofitsial'nogo priznanija termina "antropotsen" (na primere regionov Evrazii) [On the question of expediency of the official acceptance of the term „Anthropocene" (On the example of regions in Eurasia), Izvestiia vysshikh utshebnikh zavedenii. Geologiia i Razvedka 2(2019):67–73

Bolin B (2007) A history of the science and politics of climate change. Cambridge University Press, Cambridge, The role of the Intergovernmental Panel on Climate Change

Borisenkov EP (1988) Kolebaniya klimata za poslednee tysyacheletie. Gidrometeoizdat, Leningrad

Borzenkova I, Zubakov V (1984) Klimaticheskiy optimum golotsena kak model' global'nogo klimata nachala XXI veka. Meteorol Gidrol 8:69–77

Budyko M, Izrael Y (1987) Antropogennye izmeneniye klimata [Anthropogenic climate change] Gidrometeoizdat, Leningrad
Budyko MI (1988) 'Klimat kontsa dvadtsatovo veka' [Climate at the end of the 20th century]. Meteorologiya i Gidrologiya No 10:5–24
Budyko MI (1989) 'Empiricheskaya otsenka predostoyashchix izmeneniy klimata [Empirical assessments of upcoming climate changes]. Meteorologiya i Gidrologiya No 10:5–14
Budyko MI (1991) 'Analogoviy metod otsenki predostoyashchix izmeneniy klimata [The analog method for assessing upcoming climate change]. Meteorologiya i Gidrologiya No 4:39–50
Budyko M, Sedunov Y (1990) Anthropogenic climatic changes. In: Karpe H-J, Otten D, Trinidade S et al (eds) Climate and development: Climate change and variability and the resulting social, economic and technological implications. Springer Verlag, Berlin
Crowley T (1990) Are there any satisfactory geologic analogs for a future greenhouse warming?'. J Clim 3(11):1282–1292
Dinevich L, Kaplan L, Badakhova G, Kaplan G (2013) K voprosu ob izmenenii klimata' [On the question of climate change]. Sovremennye Naukoemkie Tekhnologii 2:60–63
Doose K (2021) A global problem for a divided world – climate change research in the Cold War, 1972–1991'. Cold War History. https://doi.org/10.1080/14682745.2021.1885377
Dronin N, Bychkova A (2018) Perceptions of American and Russian environmental scientists of todays's key environmental issues: a comparative analysis'. Environ Dev Sustain 20:2095–2105
Dymnikov V et al (2002) Simulation of the current climate and its changes. Izv Atmos Ocean Phys 38:S1–S24
Edwards P (2010) A vast machine. Computer models, climate data, and the politics of global warming. MIT Press, Cambridge MA
Ellingson R, Baer F, Ellsaesser H, Harshvardhan, Hoffert M (1993) Climate research in the former soviet union. Foreign Applied Sciences Assessment Center Technical Assessment Report, McLean VA
Gerasimov I (1966) Konstruktivnaya geografiya. Tsel', metody, rezul'taty. Izv Vsesoyuznogo geogr obshchestva 98(5):389–403
Gerovich S (2002) From Newspeak to Cyberspeak: a history of Soviet cybernetics. MIT Press, Cambridge
Graham L (1993) Science in Russia and the Soviet Union. Cambridge University Press, Cambridge
Graham L, Dezhina I (2008) Science in the new Russia. Indiana University Press, Bloomington, Crisis, Aid, Reform
Grigor'ev, A, (1946) Nekotory'e itogi razrabotki novykh idej v fizichechskoj geografii [Some results of the development of new ideas in physical geography]. Izv AN SSSR, Ser Geogr i Geofiz 10:139–167
Hastrup K (2013) Anticipating nature: the productive uncertainty of climate models. In: Hastrup K, Skrydstrup M (eds) The social life of climate change models: anticipating nature. Routledge, New York, pp 1–29
Haywood A et al (2008) Introduction. Pliocene climate, processes and problems. Phil Trans R Soc A 367:3–17
Haywood A et al (2011) Are there pre-quaternary geological analogues for a future greenhouse warming? Phil Trans R Soc 369:933–956
Hulme M (2013) How climate models gain and exercise authority. In: Hastrup K, Skrydstrup M (eds) The social life of climate change models: anticipating nature. Routledge, New York, pp. 30–44
Houghton J, Jenkins G, Ephraums J (1990) Climate Change. Cambridge University Press, Cambridge, The IPCC scientific sssessment
Jansen E et al (2007) Paleoclimate. In: Solomon S et al (eds) Climate change 2007: the physical basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, Cambridge University Press, pp. 433–497
Jasanoff S (2004) (ed.) States of Knowledge. The co-production of science and social order. Routledge, London & New York.
Kalmanek C (2012) The essential elements of successful innovation'. ACM SIGCOMM Computer Communication Review 42(2):105–109
Kapica A (2010) Evropu zhdet pokholodanie' [Europe will experience cooling]. Gazprom 12:11–12
Kellogg W (1977) Effects of human activities on global climate. A summary, with consideration of the implications of a possibly warmer Earth, Technical Note No. 156, Secretariat of the World Meteorological Organization, Geneva
Kondratyev K (1987) Global'ny klimat [Global climate] Gidrometeoizdat, Moscow
Kondrat'ev K, (2002) Global'noe poteplenie klimata – eto mif' [Global warming is a myth]. Nauka 25:1

Lahsen M (2013) Anatomy of dissent: a cultural analysis of climate skepticism'. Am Behav Sci 57(6):732–753
Lahsen M (2005) Seductive simulations? Uncertainty distribution around climate models'. Soc Stud Sci 35(6):895–922
Larvor B (2015) Naturalism, In: Copson A, Grayling A (eds) The Wiley Blackwell Handbook of Humanism, Hoboken, Wiley Blackwell, pp. 37–54
Livingstone D (2003) Putting science in its place: geographies of scientific knowledge. University of Chicago Press, Chicago
Lorenz E (1964) The problem of deducing the climate from governing equations'. Tellus 16:1–11
Lydolph P (1971) Soviet work and writing in climatology'. Soviet Geography: Review and Translation 7(10):637–661, 673
MacKenzie D (1990) US and Europe could fall out over climate change. New Scientist. https://www.newscientist.com/article/mg12717320-700-us-and-europe-could-fall-outover-climate-change/. Accessed 7 Mar 2022
MacCracken M, Hecht A, Budyko M, Izrael Y (1990) Prospects for future climate: a special US/USSR report on climate and climate change. CRC Press, Boca Raton
Malinovsky B (1995) Istoriia vychislitel'noi tekhniki v litsakh [The history of computing in persons]. Kit, Kiev
Marburger J (2011) Science, technology and innovation in a 21st century context'. Policy Sci 44(3):209–213
Marchuk G et al (1984) Matematicheskoe modelirovanie obshchei tsirkuliatsii atmosfery i okeana [Mathematical modeling of the general circulation of the atmosphere and ocean]. Gidrometeoizdat, Leningrad
Meleshko VP, Kattsov VM, Mirvis VM, Govorkova VA, Pavlova TV (2008) Climate of Russia in the 21st century. Part 1. New evidence of anthropogenic climate change and the state of the art of its simulation. In Russian Meteorology and Hydrology 33(6):341–350
Mokhov I (2009) Russian Climate Studies in 2003-2006, Izvestiya, Atmospheric and Oceanic Physics 45(2):169–181
Moldanov J (1998) 'Global'noe poteplenie i ozonovie dyry – naukoobraznie mify (Beseda s professorom A.P. Kapitsey) [Global warming and ozone holes are scientific myths]. Vestnik 21:14–16
Moon D (2005) The environmental history of the Russian steppes: Vasilii Dokuchaev and the harvest failure of 1891. Transactions of the RHS 15:149–174
Muryshev K et al (2009) Validating and assessing the sensitivity of the climate with an ocean general circulation model developed at the Institute of Atmospheric Physics, Russian Academy of Sciences'. Izv Atmos Ocean Phys 45(4):416–433
North G (2020) The rise of climate science. a memoir. Texas A&M University Press, College Station
Oldfield J (2016) Mikhail Budyko's (1920–2001) contributions to global climate science: from heat balances to climate change and global ecology. Wires Clim Change 7:682–692
Oldfield J (2018) Imagining climates past, present and future: Soviet contributions to the science of anthropogenic climate change, 1953–1991'. J Hist Geogr 60(41–51):42
Oreskes N, Shrader-Frechette K, Belitz K (1994) Verification, validation, and confirmation of numerical models in the Earth sciences'. Science 263(5147):641–646
Revelle R, Suess H (1957) Carbon dioxide exchange between the atmosphere and ocean and the question of an increase of atmospheric CO2 during the past decades'. Tellus 9:18–27
Rindzeviciute E (2016) The power of systems: how policy sciences opened up the Cold War world. Cornell University Press, Ithaca
Rindzeviciute E (2020) Soviet policy sciences and earth system governmentality. Mod Intellect Hist 17(1):179–208
Robinson M (2011) Pliocene climate lessons: an ongoing reconstruction of a warmer earth 3 million years ago helps test climate-change forecasts'. Am Sci 99(3):228–235
Rosol C (2015) Hauling Data. Anthropocene Analogues, Paleoceanography and Missing Paradigm Shifts', Historical Social Research / Historische Sozialforschung 40(2):37–66
Schneider S (1984) On the empirical verification of model-predicted CO2-induced climatic effects. In: Hansen J, Takashi T (eds) Climate Processes and Climate Sensitivity. American Geophysical Union, Washington, pp 187–201
Shkolnik I, Meleshko V, Kattsov V (2007) The MGO climate model for Siberia'. Russ Meteorol Hydrol 32:351–359
Skodvin T (2000) Structure and agent in the scientific diplomacy of climate change. An empirical case study of science-policy interaction in the Intergovernmental Panel on Climate Change. Kluwer, Dordrecht
Sinitsyn (1965) Drevnie klimaty Evrazii, tom 1 [Ancient climates of Eurasia, vol 1] State University Press, Leningrad

Sinitsyn (1966) Drevnie klimaty Evrazii, tom 2 [Ancient climates of Eurasia, vol 2], State University Press, Leningrad
Sinitsyn V (1967) Vvedenie v paleoklimatologiyu [Introduction to Paleoclimatology. Nedra, Leningrad
Sokolov V, Jager J, Piarev V, Nikitina, E et al. (2001) Turning points: the management of global environmental risks in the former Soviet Union, In: Social Learning Group (ed) Learning to manage global environmental risks, volume 1: a comparative history of social responses to climate change, ozone depletion, and acid rain. MIT Press, Cambridge (MA), pp 139–165
Volodin E, Dianskii N (2002) Simulation of present-day climate with a coupled atmosphere-ocean general circulation model'. Izv Atmos Ocean Phys 38(6):732–747
Weart S (1990) Interview of Mikhail Budyko by Spencer Weart on 1990 March 25, Niels Bohr Library & Archives, American Institute of Physics, College Park, MD USA. www.aip.org/history-programs/niels-bohr-library/oral-histories/31675. Accessed 7 Mar 2022
Zubakov V, Borzenkova I (1988) Pliocene palaeoclimates: past climates as possible analogues of mid-twenty-first century climate. Palaeogeogr Palaeoclimatol Palaeoecol 65(1):35–49