Evidence of Medieval Warm Period in Russia

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EVIDENCE OF MEDIEVAL WARM PERIOD IN RUSSIA

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The Medieval Warm Period (MWP) was a global climatic anomaly that encompassed a few centuries on either side of AD 1000, when temperatures in many parts of the world were even warmer than they are currently. The degree of warmth and associated changes in precipitation, however, varied from region to region and from time to time; and, therefore, the MWP was manifest differently in different parts of the world. How it behaved in Russia is the subject of this Summary.

Early evidence for the Medieval Warm Period in Russia was provided by Naurzbaev and Vaganov (2000)[1], who developed a 2200-year proxy temperature record (212 BC to 1996 AD) using tree-ring data obtained from 118 trees near the upper timberline in Siberia. And based on their results, they concluded that the warming experienced in the 20th century was "not extraordinary," and that "the warming at the border of the first and second millennia was longer in time and similar in amplitude."

One year later, Demezhko and Shchapov (2001)[2] studied a borehole extending to more than 5 km depth, reconstructing an 80,000-year history of ground surface temperature in the Middle Urals within the western rim of the Tagil subsidence (58°24' N, 59°44'E). This history revealed the existence of a number of climatic excursions, including, in their words, the "Medieval Warm Period with a culmination about 1000 years ago."

Further north, Hiller *et al*. (2001)[3] analyzed subfossil wood samples from the Khibiny mountains on the Kola Peninsula of Russia (67-68°N, 33-34°E) in an effort to reconstruct that region's climate history over the past 1500 years. In so doing, they determined that between AD 1000 and 1300 the tree-line was located at least 100-140 m *above* its current elevation, which observation, in their words, suggests that mean summer temperatures during this "Medieval climatic optimum" were "at least 0.8°C higher than today," and that "the Medieval optimum was the most pronounced warm climate phase on the Kola Peninsula during the last 1500 years."

Shortly thereafter, Krenke and Chernavskaya (2002)[4] presented an impressive overview of what was then known about the MWP within Russia, as well as throughout the world, based on historical evidence, glaciological evidence, hydrologic evidence, dendrological data, archaeological data and palynological data. And what was known is that in many places it was warmer during the MWP than it was during the latter part of the 20th century. For example, they reported that "the northern margin of boreal forests in Canada was shifted [north] by 55

[1] http://www.co2science.org/articles/V3/N10/C2.php.
[2] http://www.co2science.org/articles/V4/N39/C2.php.
[3] http://www.co2science.org/articles/V4/N30/C1.php.
[4] http://www.co2science.org/articles/V6/N30/C1.php.

km during the MWP, and the tree line in the Rocky Mountains in the southern United States and in the Krkonose Mountains was higher by 100-200 m than that observed at the present time."

In reference to the infamous "hockeystick" temperature reconstruction of Mann *et al*. (1998, 1999), the two members of the Russian Academy of Sciences wrote that "the temperature averaged over the 20th century was found to be the highest among all centennial means, although it remained within the errors of reconstructions for the early millennium." They pointedly reminded everyone, however, that "one should keep in mind that the reconstructions of the early period were based nearly entirely on tree-ring data, which, because of the features of their interpretation, tend to underestimate low-frequency variations, so the temperatures of the Medieval Warm Period were possibly underestimated," after which they went on to provide yet additional evidence for that conclusion, reporting that "the limits of cultivated land or receding glaciers have not yet exceeded the level characteristic of the early millennium."

Concentrating on data wholly from within Russia, Krenke and Chernavskaya reported large differences in a number of variables between the Little Ice Age (LIA) and MWP. With respect to the annual mean temperature of northern Eurasia, they reported an MWP to LIA drop on the order of 1.5°C. They also stated that "the frequency of severe winters reported was increased from once in 33 years in the early period of time, which corresponds to the MWP, to once in 20 years in the LIA," additionally noting that "the abnormally severe winters [of the LIA] were associated with the spread of Arctic air masses over the entire Russian Plain." Finally, they noted that the data they used to draw these conclusions were "not used in the reconstructions performed by Mann *et al*.," which perhaps explains why the Mann *et al*. temperature history of the past millennium does not depict the coolness of the LIA or the warmth of the MWP nearly as well as the more appropriately derived temperature history of Esper *et al*. (2002)[5] does.

In contradiction of another of Mann et al.'s contentions, Krenke and Chernavskaya went on to unequivocally state – on the basis of the results of their comprehensive study of the relevant scientific literature – that "the Medieval Warm Period and the Little Ice Age existed globally."

In further discussing their approach to the subject of global warming detection and attribution, the Russian Academicians stated that "an analysis of climate variations over 1000 years should help [to] reveal natural multi-centennial variations possible at present but not detectable in available 100-

[5] http://www.co2science.org/articles/V5/N13/EDIT.php.

200-year series of instrumental records." And in this endeavor, they were highly successful, as their efforts exposed the bankruptcy of the climate-alarmist claim that 20th-century warming is outside the realm of natural variability and must therefore be due to anthropogenic CO_2 emissions. And in contradiction of another of Mann *et al.*'s contentions, Krenke and Chernavskaya went on to unequivocally state - on the basis of the results of their comprehensive study of the relevant scientific literature - that "the Medieval Warm Period and the Little Ice Age existed globally."

Two years later, Esper and Schweingruber (2004)[6] analyzed treeline dynamics over western Siberia during the 20th century by comparing nine undisturbed polar sites located between 59 and 106°E and 61 and 72°N and merging information from nine sites in such a way that, in their words, "larger-scale patterns of treeline changes are demonstrated, and related to decadal-scale temperature variations," while also relating current treeline positions to former treeline locations "by documenting in-situ remnants of relict stumps and logs."

This work resulted in two main pulses of northward treeline advance being detected in the mid- and late-20th century. The first of these recruitment phases occurred between 1940 and 1960, while the second phase started around 1972 and lasted into the 1980s. These treeline advances corresponded closely to *annual* decadal-scale temperature increases; and the two researchers noted that "the lack of germination events prior to the mid-20th century indicates this is an exceptional advance," but that the relict stumps and logs found at most sites "show that this advance is part of a long-term reforestation process of tundra environments." They noted, for example, that "stumps and logs of *Larix sibirica* can be preserved for hundreds of years (Shiyatov, 1992)," and that "above the treeline in the Polar Urals such relict material from large, upright trees were sampled and dated, confirming the existence, around AD 1000, of a forest treeline 30 m above the late 20th century limit (Shiyatov, 2003)." They also state that "this previous forest limit receded around 1350, perhaps caused by a general cooling trend (Briffa, 2000; Esper *et al*., 2002."

"Synchronous with the advance shown from the western Siberian network," according to Esper and Schweingruber, a mid-20th century tree recruitment period was occurring in "central Sweden (Kullmann, 1981), northern Finland (Kallio, 1975), northern Quebec (Morin and Payette, 1984) and the Polar Urals (Shiyatov, 1992)." Therefore, together with their own results from Asia, they concluded that "these findings from Europe and North America support a circumpolar trend, likely related to a global climate warming pattern," thereby also recognizing that these data demonstrate the positive response of the biosphere to the warming that accompanied the demise of the Little Ice Age and the establishment of the Current Warm Period. In addition, they demonstrate the existence of the *warmer-than-present* multi-century period centered around AD 1000 that we know today as the Medieval Warm Period.

One year later, Kalugin *et al*. (2005)[7] analyzed sediment cores from Lake Teletskoye in the Altai Mountains of Southern Siberia (51°42.90'N, 87°39.50'E), producing a multi-proxy climate record spanning the past 800 years. Analyses of this multi-proxy record revealed several distinct

[6] http://www.co2science.org/articles/V7/N19/C1.php.
[7] http://www.co2science.org/articles/V8/N27/C2.php.

climatic periods over the past eight centuries. With respect to temperature, the regional climate was relatively warm with high terrestrial productivity from AD 1210 to 1380. Thereafter, however, temperatures cooled, reaching peak deterioration between 1660 and 1700, which time period, in the words of the four researchers, "corresponds to the age range of the well-known Maunder Minimum (1645-1715)" and is "in agreement with the timing of the Little Ice Age in Europe (1560-1850)," while recovery to prior-level warmth did not occur until the late 20th century.

With respect to moisture and precipitation, Kalugin *et al*. stated that the period between 1210 and 1480 was more humid than that of today, while the period between 1480 and 1840 was more arid. In addition, they reported three episodes of multi-year drought (1580-1600, 1665-1690 and 1785-1810), which findings are in agreement with other historical data and tree-ring records from the Mongolia-Altai region (Butvilovskii, 1993; Jacoby *et al*., 1996; Panyushkina *et al*., 2000). In addition, their findings prove problematic for the climate-alarmist claim that global warming will lead to more severe droughts, as *all* of the major multi-year droughts detected in this study occurred during the *cool* phase of the 800-year record.

Contemporaneously, Mackay *et al*. (2005)[8] analyzed paleolimnological data obtained from a sediment core taken from the south basin of Lake Baikal, Russia, in an effort to reconstruct the climatic history of this area of central Asia over the past millennium. Their use of cluster analysis in doing so identified three significant zones of variability in the sediment core that were coincident with the Medieval Warm Period (c. 880 AD - c. 1180 AD), the Little Ice Age (c. 1180 AD - 1840 AD) and the Current Warm Period. Although it was not possible to obtain direct temperature estimates in this study, the seven scientists say their diatom data did in fact support the idea that "the period known as the MWP in the Lake Baikal region was a relatively warm one." Then, following the MWP, diatom species shifted toward taxa indicative of colder climates, implying maximum snow depth values during the Maunder

The fact that the warming that brought the world the Current Warm Period began around 1750 AD, or nearly 100 years before the modern rise in atmospheric CO_2 concentration, should be evidence enough to argue that the planet's current warmth is the result of nothing more than the most recent and expected upward swing of this natural climatic oscillation.

[8] http://www.co2science.org/articles/V8/N31/C3.php.

Minimum (1645-1715 AD), after which the diatom-derived snow accumulation data indicated a warming trend in the Lake Baikal region that began as early as c. 1750 AD. And the fact that the warming that brought the world the Current Warm Period began around 1750 AD, or nearly 100 years before the modern rise in atmospheric CO_2 concentration, should be evidence enough to argue that the planet's current warmth is the result of nothing more than the most recent *and expected* upward swing of this natural climatic oscillation.

During this same time period, and noting that "dead trees located above the current tree-line ecotone provide evidence of the dynamic behavior in the location of the tree line in the recent past (Shiyatov, 1993, 2003)," Mazepa (2005)[9] reported that "previous studies have concluded that increases in tree-line elevation, and associated increases in tree abundance within the transient tree-line ecotone, are associated with extended warm periods (Tranquillini, 1979; Kullman, 1986; Payette *et al*., 1989; Lloyde and Fastie, 2003; Lloyd *et al*., 2003; Grace *et al*., 2002; Helama *et al*., 2004)." And thus it was that similar data were used by the lone researcher to evaluate the uniqueness of Polar Ural tree-line and density response "to what is widely considered to be anomalous 20th-century warming."

More specifically, Mazepa examined evidence of tree growth dynamics along a continuous altitudinal transect 860 meters long and 40-80 meters wide on the eastern slope of the Polar Ural Mountains (66°48'57"N, 65°34'09"E) by repeating what Shiyatov had done four decades earlier, discovering that (1) "a large number of well-preserved tree remains can be found up to 60-80 meters above the current tree line, some dating to as early as a maximum of 1300 years ago," and that (2) "the earliest distinct maximum in stand density occurred in the 11th to 13th centuries, coincident with Medieval climatic warming," when "summer air temperatures may have been 0.42-0.56°C warmer than they were over the last decades of the 20th century."

Two years later, while working with a sediment core extracted from the central and deepest part of Lake Teletskoye in the northeastern part of the Altai Mountains in southern Siberia (51°43'N, 87°39'E), Andreev *et al*. (2007)[10] analyzed pollen and charcoal stratigraphy to develop what they described as "the first detailed climate and vegetation reconstruction for the last millennium in the northern Altai Mountains." And what did they find? Quoting the six researchers, "dense Siberian pine forest dominated the area around the lake at least since ca. AD 1020," when they say that "climate conditions were similar to modern." Then, "between AD 1100 and 1200, a short dry period with increased fire activity occurred," and "around AD 1200, climate became more humid with the temperatures probably higher than today." This period of rather stable climate, "possibly reflecting [the] Medieval Warm Epoch, lasted until AD 1410," after which "slightly drier climate conditions occurred between AD 1410 and 1560." Thereafter, they say that "a subsequent period with colder and more arid climate conditions between AD 1560 and 1820 is well correlated with the Little Ice Age," after which they found evidence for a climate warming they "inferred from the uppermost pollen spectra, accumulated after AD 1840," which was "consistent with the instrumental data" of the modern period.

[9] http://www.co2science.org/articles/V9/N49/C3.php.
[10] http://www.co2science.org/articles/V10/N33/C2.php.

Consequently, it is clear from Andreev *et al.*'s findings that the Altai Mountain region of southern Siberia displays the characteristic millennial-scale cycling of climate from Medieval Warm Period to Little Ice Age to Current Warm Period conditions that is characteristic of most of the rest of the world. In addition, it is of interest to note that from approximately AD 1200 to 1410, they concluded that temperatures in the region of their study were "probably higher than today," providing yet another example of times and places when and where *low-CO_2 Medieval* Warm Period temperatures were likely higher than *high-CO_2 Current* Warm Period temperatures.

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Also working at Teletskoye Lake (51°39'N, 87°40'E) in the Altai Mountains of southern Siberia, Kalugin *et al.* (2007)[11] collected several sediment cores from the deepest area of the lake, for which they measured the spectra of numerous elements - including Ba, Cd, Ce, I, La, Mo, Nb, Rb, Sb, Sn, Sr, Th, U, Y, Zr - after which "artificial neural networks (Veelenturf, 1995) were used for reconstruction of annual temperature and precipitation by sediment properties (Smolyaninova *et al.*, 2004)." And what did *they* find? The six scientists say that "a global cold period, the Little Ice Age with Maunder minimum, is clearly designated, as well as global warming during the 19-20th centuries," all of which also implies the existence of the Medieval Warm Period that preceded the Little Ice Age. In fact, from their plot of the pertinent data, it can be seen that the mean peak temperature of the latter part of the Medieval Warm Period (when there was fully 100 ppm *less* CO_2 in the air than there is currently) was about 0.5°C *higher* than the mean peak temperature of the Current Warm Period, which occurred at the end of the record.

Contemporaneously, Matul *et al.* (2007)[12] studied the distributions of different species of siliceous microflora (diatoms), calcareous microfauna (foraminifers) and spore-pollen assemblages found in sediment cores retrieved from 21 sites on the inner shelf of the southern and eastern Laptev Sea, starting from the Lena River delta and moving seaward between about 130 and 134°E and

[11] http://www.co2science.org/articles/V10/N36/C1.php.
[12] http://www.co2science.org/articles/V10/N48/C2.php.

stretching from approximately 71 to 78°N, which cores were acquired by a Russian-French Expedition during the cruise of R/V *Yakov Smirnitsky* in 1991. This endeavor revealed, in the words of the five Russian researchers, that "(1) the warming at the beginning of the Common Era (terminal epoch of the Roman Empire) during ~1600-1900 years BP; (2) the multiple, although low-amplitude, cooling episodes at the beginning of the Middle Ages, 1100-1600 years BP; (3) the Medieval Warm Period, ~600-1100 years BP; (4) the Little Ice Age, ~100-600 years BP, with the cooling maximum, ~150-450 years BP; and (5) the 'industrial' warming during the last 100 years." And "judging from the increased diversity and abundance of the benthic foraminifers, the appearance of moderately thermophilic diatom species, and the presence of forest tundra (instead of tundra) pollen," Matul *et al*. concluded that "the Medieval warming exceeded the recent 'industrial' one."

Creeping one year closer to the present, MacDonald *et al*. (2008)[13] conducted an analysis of past changes in the location of the northern Russian treeline - as reconstructed from tree-ring data and radiocarbon-dated subfossil wood - in an attempt to answer the question: "Has the pattern of recent warming over the late nineteenth and the twentieth centuries caused significant changes in the density of trees at the treeline and/or an extension of the geographical location of the treeline?" And their answer? They report that "temperature increases over the past century are already producing demonstrable changes in the population density of trees, but these changes have not yet generated an extension of conifer species' limits to or beyond the former positions occupied during the Medieval Warm Period (MWP: *ca* AD 800-1300) or the Holocene Thermal Maximum treeline extension (HTM: broadly taken here to be *ca* 10,000-3,000 years ago)."

On the Khibiny uplands of the central Kola Peninsula, for example, they write that "the treeline was located 100-140 m higher in elevation than today during the MWP," and that "forest has yet to recolonize these elevations (Kremenetski *et al*., 2004)." Likewise, of the northern Polar Urals they say that "the treeline was at its highest elevation during the MWP between *ca* AD 900 and 1300 when it reached 340 m," after which it "descended to approximately 270 m during the Little Ice Age and then ascended to its present elevation of approximately 310 m during the recent warming of the late nineteenth and twentieth centuries."

As for what this all means, the three researchers conclude that "at the Russian sites studied, the impact of twentieth century warming has not yet compensated fully for the mortality and range constriction caused by the cold temperatures of the Little Ice Age," and they note that "these results are similar to observations in some other northern treeline regions such as uplands in eastern Quebec and interior Labrador where *Picea mariana* (P. Mill.) B.S.P. and *Picea glauca* (Moench) Voss trees remain below their pre-Little Ice Age limits despite recent warming (Gamache and Payette, 2005; Payette, 2007)," which warming has likely not yet equaled that of the MWP in either magnitude or duration.

In bringing this Summary to an end, a brief review of the paper of Panin and Nefedov (2010)[14] would seem to be in order. Noting that the long-term decrease in seasonal peaks of water

[13] http://www.co2science.org/articles/V11/N32/C2.php.
[14] http://www.co2science.org/articles/V13/N29/C2.php.

levels allows the settling of people in low geomorphic locations, such as river and lake floodplains, while a rise in flood levels causes settlements to be shifted to higher elevations, they made the logical assumption that "ancient settlements could not persist under the impact of regular inundations." And, therefore, in a study of the Upper Volga and Zapadnaya Dvina Rivers of Russia, the two researchers determined "the geomorphological and altitudinal positions of [human] occupational layers corresponding to 1224 colonization epochs at 870 archaeological sites in river valleys and lake depressions in southwestern Tver province," identifying "a series of alternating low-water (low levels of seasonal peaks, many-year periods without inundation of flood plains) and high-water (high spring floods, regular inundation of floodplains) intervals of various hierarchical rank."

This work revealed, in Panin and Nefedov's words, that "low-water epochs coincide with epochs of relative warming, while high-water epochs [coincide] with cooling epochs," because "during the climate warming epochs, a decrease in duration and severity of winters should have resulted in a drop in snow cover water equivalent by the snowmelt period, a decrease in water discharge and flood stage, and a decrease in seasonal peaks in lake levels," while noting that "a model of past warming epochs can be the warming in the late 20th century." They also report finding that "in the Middle Ages (1.8-0.3 Ky ago), the conditions were favorable for long-time inhabiting [of] river and lake floodplains, which are subject to inundation nowadays." In addition, their results indicate that of this time interval, the period AD 1000-1300 hosted the greatest number of floodplain occupations.

Interestingly, Panin and Nefedov state that this last period and other "epochs of floodplain occupation by humans in the past can be regarded as hydrological analogues of the situation of the late 20th-early current century," which they say "is forming under the effect of directed climate change." And this relationship clearly implies that the current level of warmth in the portion of Russia that hosts the Upper Volga and Zapadnaya Dvina Rivers is not yet as great as it was during the AD 1000-1300 portion of the Medieval Warm Period.

Considering the full spectrum of studies included in this Summary, it would appear that a goodly portion of the Medieval Warm Period throughout Russia was somewhat warmer than what has so far been experienced there during the Current Warm Period.

In conclusion, and considering the full spectrum of studies included in this Summary, it would appear that a goodly portion of the Medieval Warm Period throughout Russia was somewhat warmer than what has so far been experienced there during the Current Warm Period. And

since the MWP held sway when the atmosphere's CO_2 concentration was something on the order of 285 ppm, as compared to the 400 ppm of today, it would appear that the air's CO_2 content has had essentially nothing to do with earth's near-surface air temperature throughout the entire Holocene, when the air's CO_2 concentration at times dropped as low as 250 ppm. Other factors have clearly totally dominated.

REFERENCES

Andreev, A.A., Pierau, R., Kalugin, I.A., Daryin, A.V., Smolyaninova, L.G. and Diekmann, B. 2007. Environmental changes in the northern Altai during the last millennium documented in Lake Teletskoye pollen record. *Quaternary Research* **67**: 394-399.

Briffa, K.R. 2000. Annual climate variability in the Holocene: Interpreting the message of ancient trees. *Quaternary Science Reviews* **19**: 87-105.

Butvilovskii, V.V. 1993. *Paleogeography of the Late Glacial and Holocene on Altai*. Tomsk University, Tomsk.

Demezhko, D.Yu. and Shchapov, V.A. 2001. 80,000 years ground surface temperature history inferred from the temperature-depth log measured in the superdeep hole SG-4 (the Urals, Russia). *Global and Planetary Change* **29**: 167-178.

Esper, J., Cook, E.R. and Schweingruber, F.H. 2002. Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability. *Science* **295**: 2250-2253.

Esper, J. and Schweingruber, F.H. 2004. Large-scale treeline changes recorded in Siberia. *Geophysical Research Letters* **31**: 10.1029/2003GL019178.

Gamache, I. and Payette, S. 2005. Latitudinal response of subarctic tree lines to recent climate change in Eastern Canada. *Journal of Biogeography* **32**: 849-862.

Grace, J. Berninger, F. and Nagy, L. 2002. Impacts of climate change on the tree line. *Annals of Botany* **90**: 537-544.

Helama, S., Lindholm, M., Timonen, M. and Eronen, M. 2004. Dendrochronologically dated changes in the limit of pine in northernmost Finland during the past 7.5 millennia. *Boreas* **33**: 250-259.

Hiller, A., Boettger, T. and Kremenetski, C. 2001. Medieval climatic warming recorded by radiocarbon dated alpine tree-line shift on the Kola Peninsula, Russia. *The Holocene* **11**: 491-497.

Jacoby, G.C., D'Arrigo, R.D. and Davaajatms, T. 1996. Mongolian tree rings and 20th century warming. *Science* **273**: 771-773.

Kallio, P. 1975. Reflections on the adaptations of organisms to the northern forest limit in Fennoscandia. Paper Presented at the Circumpolar Conference on Northern Ecology, National Research Council, Ottawa, Canada.

Kalugin, I., Daryin, A., Smolyaninova, L., Andreev, A., Diekmann, B. and Khlystov, O. 2007. 800-yr-long records of annual air temperature and precipitation over southern Siberia inferred from Teletskoye Lake sediments. *Quaternary Research* **67**: 400-410.

Kalugin, I., Selegei, V., Goldberg, E. and Seret, G. 2005. Rhythmic fine-grained sediment deposition in Lake Teletskoye, Altai, Siberia, in relation to regional climate change. *Quaternary International* **136**: 5-13.

Kremenetski, K.V., Boettger, T., MacDonald, G.M., Vaschalova, T., Sulerzhitsky, L. and Hiller, A. 2004. Medieval climate warming and aridity as indicated by multiproxy evidence from the Kola Peninsula, Russia. *Palaeogeography and Palaeoclimate* **209**: 113-125.

Krenke, A.N. and Chernavskaya, M.M. 2002. Climate changes in the preinstrumental period of the last millennium and their manifestations over the Russian Plain. *Isvestiya, Atmospheric and Oceanic Physics* **38**: S59-S79.

Kullmann, L. 1981. Pattern and process of present tree-limits in the Tarna region, southern Swedish Lapland. *Fennia* **169**: 25-38.

Kullmann, L. 1986. Late Holocene reproductional patterns of Pinus sylvestris and Picea abies at the forest limit in central Sweden. *Canadian Journal of Botany* **64**: 1682-1690.

Lloyd, A.H. and Fastie, C.L. 2003. Recent changes in treeline forest distribution and structure in interior Alaska. *Ecoscience* **10**: 176-185.

Lloyd, A.H., Rupp, T.S., Fastie, C.L. and Starfield, A.M. 2003. Patterns and dynamics of tree line advance on the Seward Peninsula, Alaska. *Journal of Geophysical Research* **108**: 10.1029/2001JD000852.

MacDonald, G.M., Kremenetski, K.V. and Beilman, D.W. 2008. Climate change and the northern Russian treeline zone. *Philosophical Transactions of the Royal Society B* **363**: 2285-2299.

Mackay, A.W., Ryves, D.B., Battarbee, R.W., Flower, R.J., Jewson, D., Rioual, P. and Sturm, M. 2005. 1000 years of climate variability in central Asia: assessing the evidence using Lake Baikal (Russia) diatom assemblages and the application of a diatom-inferred model of snow cover on the lake. *Global and Planetary Change* **46**: 281-297.

Mann, M.E., Bradley, R.S. and Hughes, M.K. 1998. Global-scale temperature patterns and climate forcing over the past six centuries. *Nature* **392**: 779-787.

Mann, M.E., Bradley, R.S. and Hughes, M.K. 1999. Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. *Geophysical Research Letters* **26**: 759-762.

Matul, A.G., Khusid, T.A., Mukhina, V.V., Chekhovskaya, M.P. and Safarova, S.A. 2007. Recent and late Holocene environments on the southeastern shelf of the Laptev Sea as inferred from microfossil data. *Oceanology* **47**: 80-90.

Mazepa, V.S. 2005. Stand density in the last millennium at the upper tree-line ecotone in the Polar Ural Mountains. *Canadian Journal of Forest Research* **35**: 2082-2091.

Morin, A. and Payette, S. 1984. Expansion recente du meleze a la limite des forets. (Quebec nordique). *Canadian Journal of Botany* **62**: 1404-1408.

Naurzbaev, M.M. and Vaganov, E.A. 2000. Variation of early summer and annual temperature in east Taymir and Putoran (Siberia) over the last two millennia inferred from tree rings. *Journal of Geophysical Research* **105**: 7317-7326.

Panin, A.V. and Nefedov, V.S. 2010. Analysis of variations in the regime of rivers and lakes in the Upper Volga and Upper Zapadnaya Dvina based on archaeological-geomorphological data. *Water Resources* **37**: 16-32.

Panyushkina, I.P., Adamenko, M.F., Ovchinnikov, D.V. 2000. Dendroclimatic net over Altai Mountains as a base for numerical paleogeographic reconstruction of climate with high time resolution. In: *Problems of Climatic Reconstructions in Pliestocene and Holocene 2*. Institute of Archaeology and Ethnography, Novosibirsk, pp. 413-419.

Payette, S. 2007. Contrasted dynamics of northern Labrador tree lines caused by climate change and migrational lag. *Ecology* **88**: 770-780.

Payette, S., Filion, L., Delwaide, A. and Begin, C. 1989. Reconstruction of tree-line vegetation response to long-term climate change. *Nature* **341**: 429-432.

Shiyatov, S.G. 1992. The upper timberline dynamics during the last 1100 years in the Polar Ural mountains. In: Frenzel, B. (Ed.) *Oscillations of the Alpine and Polar Tree Limits in the Holocene*. Fischer, Stuttgart, Germany, pp. 195-203.

Shiyatov, S.G. 1993. The upper timberline dynamics during the last 1100 years in the Polar Ural Mountains. *European Palaeoclimate and Man* **4**: 195-203.

Shiyatov, S.G. 2003. Rates of in the upper treeline ecotone in the Polar Ural Mountains. *Pages Newsletter* **11**: 8-10.

Smolyaninova, L.G., Kalugin, I.A. and Daryin, A.V. 2004. Technique of receiving empiri-mathematical interdependence models between climatic parameters and litologi-geochemical

character of bottom deposits. *Computer Technology* **9**: *Mathematic, Mechanic, Computing* **3**: 43-46.

Tranquillini, W. 1979. *Physiological Ecology of the Alpine Timberline*. Springer-Verlag, Berlin, Germany.

Veelenturf, L.P.J. 1995. Analysis and applications of artificial neural networks. *Computer Science* **259**.

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