forests

MDPI

Article

Climate Response of Larch and Birch Forests across an Elevational Transect and Hemisphere-Wide Comparisons, Kamchatka Peninsula, Russian Far East

Clara Deck [1,*], Gregory Wiles [1,2], Sarah Frederick [1], Vladimir Matsovsky [3], Tatiana Kuderina [3], Rosanna D'Arrigo [2], Olga Solomina [2,3] and Nicholas Wiesenberg [1]

[1] Department of Geology, The College of Wooster, Wooster, OH 44691, USA; gwiles@wooster.edu (G.W.); sfrederick15@wooster.edu (S.F.); nwiesenberg@wooster.edu (N.W.)

[2] Lamont-Doherty Tree Ring Lab, Columbia University, Palisades, NY 10964, USA; rdd@ldeo.columbia.edu (R.D.); olgasolomina@yandex.ru (O.S.)

[3] Institute of Geography, Russian Academy of Sciences, Moscow, 119991, Russia; matskovsky@gmail.com (V.M.); tmkud@yandex.ru (T.K.)

* Correspondence: cdeck17@wooster.edu; Tel.: +1-(708)-207-5038

Academic Editor: Timothy A. Martin
Received: 14 July 2017; Accepted: 21 August 2017; Published: 27 August 2017

Abstract: Kamchatka's forests span across the peninsula's diverse topography and provide a wide range of physiographic and elevational settings that can be used to investigate how forests are responding to climate change and to anticipate future response. Birch (*Betula ermanii* Cham.) and larch (*Larix gmelinii* (Rupr.) Kuzen) were sampled at eight new sites and together with previous collections were compared with monthly temperature and precipitation records to identify their climate response. Comparisons show that tree-ring widths in both species are primarily influenced by May through August temperatures of the current growth year, and that there is a general increase in temperature sensitivity with altitude. The ring-width data for each species were also combined into regional chronologies. The resulting composite larch chronology shows a strong resemblance to a Northern Hemisphere (NH) tree-ring based temperature reconstruction with the larch series tracking NH temperatures closely through the past 300 years. The composite birch ring-width series more closely reflects the Pacific regional coastal late summer temperatures. These new data improve our understanding of the response of forests to climate and show the low frequency warming noted in other, more continental records from high latitudes of the Northern Hemisphere. Also evident in the ring-width record is that the larch and birch forests continue to track the strong warming of interior Kamchatka.

Keywords: dendrochronology; dendroclimatology; Kamchatka; tree rings; *Betula ermanii*; *Larix gmelinii*

1. Introduction

The future of the boreal forests in Siberia and eastern Asia with a changing climate remains uncertain. Some modeling studies suggest an increase in productivity in the coming decades with a warming climate [1], whereas other models point to a large-scale change in the composition of the ecosystems from coniferous forest to steppe and grasslands [2]. Given that larch (*Larix* spp.) forests are important and extensive global coniferous forests, and birch (*Betula* spp.) are significant along the eastern margin of Asia and in the Northern Hemisphere as a whole, we have undertaken a tree-ring investigation of the climatic controls in Kamchatka of past and recent changes in tree growth of these important species. Since larch forests in Siberia and the Far East are being managed in different way, they are susceptible to illegal logging and fire, and are underlain by discontinuous melting permafrost north of 57 degrees, the future of the forests remains uncertain [1,2]. Tree rings can be used to assess past changes in forest productivity and climate, and also can be used to assess recent changes in forest growth with changing climate conditions. Interior regions of Kamchatka can be considered a microcosm of the larger Siberian forest ecosystem, although with heavier precipitation due to moist air from the Pacific Ocean and the Sea of Okhotsk and a milder subarctic climate than interior Siberia [3]. The interior Kamchatkan larch forest can also serve as a case study for general forest change with increased warming. Kamchatkan forests have undergone logging and disturbance, but they are more pristine than many other boreal forests and thus provide a good study site to draw distinctions between more human impacted areas [4].

The Kamchatka Peninsula (Russian Federation) is located in the western North Pacific, on the eastern margin of Asia where the prevailing climate is determined in large part by its complex geography, with a continental interior valley surrounded by the cool and more maritime ocean-facing flanks of the Sredinny and Eastern Ranges (Figure 1). The North Pacific lies to the east of the peninsula and the Sea of Okhotsk to the west. Generally, it is considered to have a subarctic climate with an annual precipitation between 600–1100 mm in the high mountains and up to 2500 mm along the coasts. Mean annual temperature is about 0 °C in the coastal south at the capital Petropavlovsk-Kamchatsky and in the interior the rural locality of Klyuchi to the north experiences an extreme range of temperatures from 19 °C in summer to −41 °C in winter. The climate of the region is sensitive to the intensity of the summer North Pacific High and the winter, Aleutian Low. In winter the Siberian High brings cold, dry weather to the region [5]. Early summer sea ice in the Sea of Okhotsk brings cold air to the peninsula and competes with the summer monsoonal influence and the Pacific subtropical high, which brings warm, moist air masses in from the south and east.

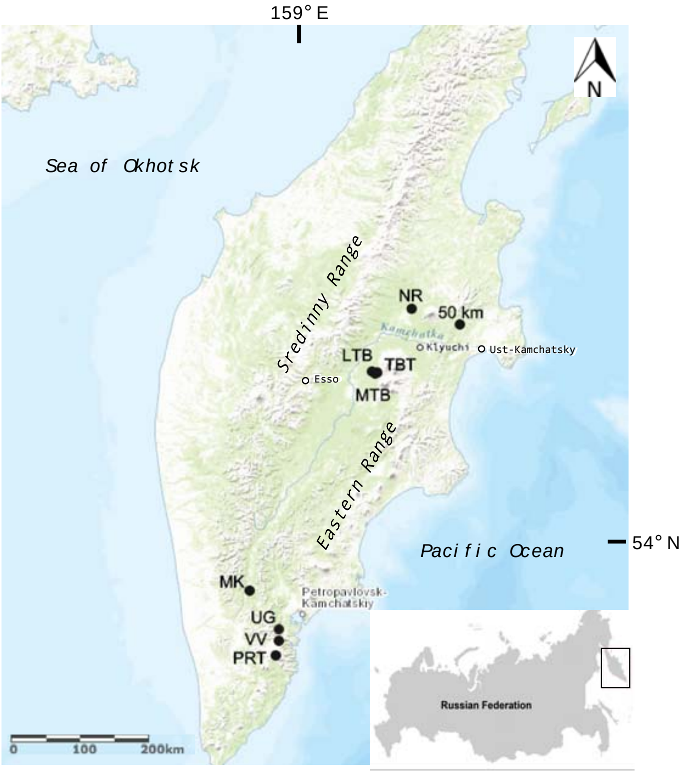


Figure 1. Locations of tree-ring chronology sites on the Kamchatka Peninsula, Russia. Also shown are Klyuchi, Ust Kamchatsky and Petropavlovsk-Kamchtasky meteorological stations that were used in comparisons with ring-width series. NR: North Road; LTB: Lower Tobalchik Volcano; TBT: Tobalchik Volcano; MTB: Mid-Tobalchik Volcano; MK: Malkee; UG: Garchche Sopa; VV: Viluchi Volcano; PRT: Paratunka.

The two dominant mountain ranges, 29 active volcanoes and over 300 extinct volcanoes (Figure 1) [6] provide a complex terrain in which trees grow in a wide range of settings and the differences in tree growth with altitude and location can be investigated. This information is important in identifying how trees are responding to changes in climate, and to improve sampling strategies for optimal climate sensitivity for dendroclimatology.

Recently, there has been increased attention focused on the dendroclimatic potential of tree species on the Kamchatka Peninsula in the Russian Far East [3]. The region has experienced almost 2 °C warming of annual temperatures over the last 100 years. Several tree-ring chronologies have been generated on Sakhalin Island, and the Asian mainland during a 2013–2014 field campaign [7,8]. These new data build on previous tree-ring based temperature reconstructions for the Peninsula [9–11]. The bulk of the previous work has been conducted with larch (*Larix gmelinii* (Rupr.) Kuzen) due to its long-life span and wide distribution across Kamchatka, especially in the central lowlands where it can be found at altitudes as high as 1000 m in the bordering mountains [3,12]. This interior forest is often referred to as a Conifer Island, which occurs with Japanese white birch (*Betula platyphylla* Sukaczev), poplar (*Populus tremula* L.), Manchurian alder (Alnus hirsute Turcz), larch (*Larix gmelinii* (Rupr.) Kuzen, syn. *Larix cajanderi* Mayr.), Siberian dwarf pine (*Pinus pumila* Pall.) and Ajan spruce (*Picea ajanensis* Fisch., syn. *Picea jezoensis* Sieb. et Zucc.) [13]. Of Kamchatka's coniferous forests, only 2.1 percent (350,000 ha) remain undisturbed by logging or fire [14] and assembling tree-ring chronologies from undisturbed old-growth sites is a challenge.

Gostev et al. [9] conducted one of the first dendroclimatic studies for Kamchatka, and generated a larch based tree-ring reconstruction that explained 38% of the variance in May-June temperatures back to AD 1670. Other studies have also reported that larch ring widths are positively related to early summer temperature [12,15,16] and that in general larch growth has been responding favorably (increased growth) to recent warming [16]. In addition, interior Siberian studies have found that larch in the northern taiga region has responded positively to summer warming [17,18], but that there is a negative tree growth response with environmental warming in continental dry regions [19].

Stone birch (*Betula ermanii* Cham.) is the most extensive deciduous tree found in lower elevation forests, and its abundance is a distinctive feature of Kamchatka's vegetation [3,4]. These trees dominate the lowlands and middle zone of the peninsula's mountainous regions and coastal margins [14]. Due to complex ring boundaries and its shorter life span, birch has not been used as extensively in tree-ring research [13]. However, some studies have noted that this widespread species shows promise for dendroclimatic studies [9,11–13]. In particular, Sano et al. [10] developed a 247-year ring-width chronology at Paratunka (Figure 1) for *Betula ermanii*. They determined that ring width was primarily controlled by July–August temperature and developed a well-verified temperature reconstruction using meteorological records from Petropavlovsk-Kamchatsky.

Herein, we determine how birch and larch trees respond to climate along elevational gradients of the Kamchatka Peninsula, and compare the climate response of the two species. We now have ring-width data from an additional eight new, well replicated sites in two areas of Kamchatka (Figure 1), the northeast region, near Klyuchi, and in the south, near Petropavlovsk-Kamchatsky. Besides examining the elevational climate response, we study the low frequency response of the larch series as a record of regional summer temperature and compare it with a Northern Hemisphere tree-ring based temperature reconstruction [20].

2. Materials and Methods

Tree-ring samples of birch and larch were collected from nine sites during the summer of 2014 (Table 1). Five sites are located in the northeastern region of the peninsula, near Klyuchi, and four birch sites are from the Petropavlovsk area in the southeast (Figure 1). Eight of the chronologies are unpublished and one, the Paratunka birch site (PRT; Figure 1) was sampled previously [11] and has been updated here (Table 1).

Table 1. Chronology descriptions.

Site	Location	Altitude (m)	Species	Period of Record	Number of Cores/Trees
54 km from Ust (50 km)	56.52759° N, 161.97069° E	112	*Betula ermanii*	1814–2014 (200 years)	21/14
North Road (NR)	56.70416° N, 160.95035° E	95–150	*Betula ermanii*	1823–2014 (191 years)	21/16
Lower Tobalchik Volcano (LTB)	55.97215° N, 160.13524° E	486	*Larix gmelinii*	1675–2014 (339 years)	34/17
Mid-Tobalchik Volcano (MTB)	55.94931° N, 160.19910° E	743	*Larix gmelinii*	1674–2014 (340 years)	41/20
Tobalchik Volcano (TBT)	55.9567° N, 160.23132° E	944	*Larix gmelinii*	1653–2014 (361 years)	63/31
Garchche Sopa (UG)	52.8243° N, 158.1664° E	68	*Betula ermanii*	1763–2014 (252 years)	28/17
Viluchi Volcano (VV)	52.68926° N, 158.16354° E	410	*Betula ermanii*	1792–2014 (223 years)	22/13
Malkee (MK)	53.32233° N, 157.54709° E	278	*Betula ermanii*	1841–2014 (173 years)	23/13
Paratunka * (PRT)	52.50° N, 158.10° E	864	*Betula ermanii*	1755–2014 (259 years)	73/41

Tree-ring width chronologies from this study; * Chronology PRT was updated from Sano et al. [11] using collections in this study.

Two to three cores were extracted from each tree for at least twenty trees per stand (Table 1). Cores were sanded and prepared for tree-ring analysis. Rings were counted, cross dated and measured to a precision of ±0.001 mm using a Velmex measuring system (Velmex, Inc., Bloomfield, NY, USA) and the program Measure J2X (Version 4, VoorTech Consulting, Holderness, NH, USA). We used the COFECHA computer program [21] to verify cross dating and as a tool to assess the quality of the dating [22].

Individual ring-width series were standardized using ARSTAN software, initially using a negative exponential curve fit for the individual series [23]. The resulting ring-width chronologies were then correlated with mean monthly temperature and precipitation data from weather stations in Klyuchi and Petropavlovsk-Kamchatsky. These station data were obtained from the KNMI Climate Explorer [24,25]. The Klyuchi mean temperature record spans the years 1908–2015, with incomplete data from 1991 to 2004. These missing values were supplemented with other data [26]. There were also missing years in the Petropavlovsk temperature and precipitation records, however, no suitable supplemental data was available. Our tree-ring sites are located 40–70 km from the meteorological stations and reflect similar environments, elevations and vegetation, and thus are appropriate for our comparisons.

Two composite chronologies, one for larch and one for birch, were combined from our new sites together with those of the previous studies within each region (the south for birch and the interior for larch). The composite larch series were standardized using signal-free Regional Curve Standardization (RCS) [27,28]. This technique aligns the tree ring width series by their biological age, and then fits a regional curve to the composite series that is used in standardization [29]. We used signal-free RCS because of the relatively large sample size of the combined ring-width series and the relatively uniform negative exponential fit for detrending. The resulting chronology maintains low frequency variability [29] and the signal-free aspect also minimizes problems associated with RCS performed on contemporarily growing trees [28].

The combined 331 ring width series for larch date back to the late-16th century, which consists of our new collections from the Tobalchik Volcano (TBT Figure 2) with those of Gostev et al. [9], Sano et al. [16] and Solomina et al. [12]. For the birch collection, we chose conservative detrending using negative exponential curve fits in standardization using ARSTAN [20]. The relatively smaller sample size (n = 113) compared with larch (n = 331) and the shorter series length and relatively weaker climate signal and less uniform growth curves did not merit the use of RCS in this case. The composite of 113 birch series extends to the mid-18th century and includes our new records and those of Sano et al. [11] (Table 1, Figures 2 and 3). For both composite series, we used the expressed population signal (EPS) [30,31] to assess the signal strength of the chronology back in time and to indicate when a critical EPS of 0.85 is exceeded (Figure 2).

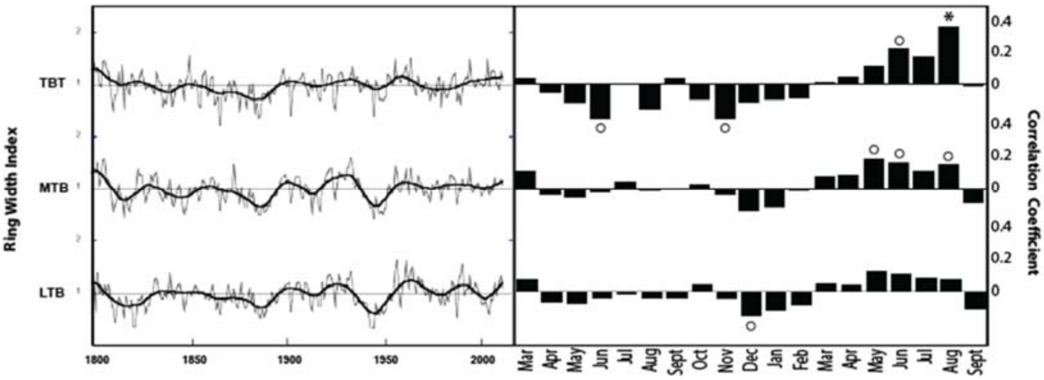


Figure 2. Left, larch chronologies starting from 1800, ordered with respect to increasing altitude (over a 500 meter difference) from bottom to top. EPS statistic is greater than 0.85 for the entire interval shown. Thick line shows values smoothed with a 6% weighted curve. Right, correlations with Klyuchi mean temperature for a 19 month dendroclimatic year, March–December of the previous year through September of the current growth year. ° denotes a correlation significant at a 90% confidence level, whereas * a correlation significant at the 99% confidence level.

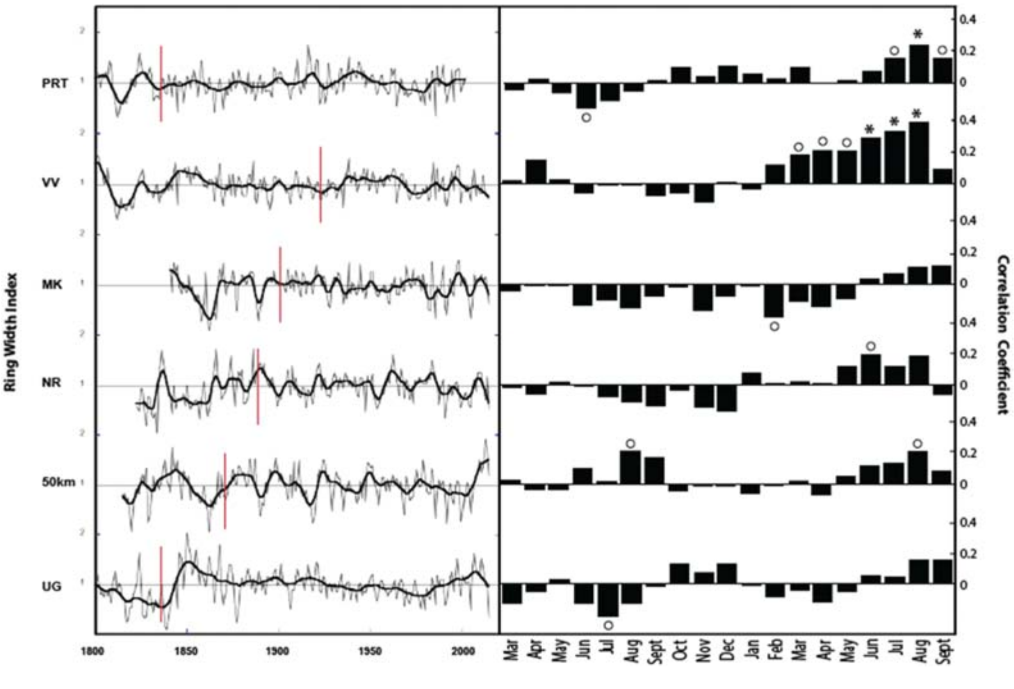


Figure 3. Left, Birch chronologies starting from 1800, ordered in increasing altitude from bottom to top Label elevations. Red vertical lines indicate when EPS exceeds 0.85. Thick line shows values smoothed with a 6% weighted curve. Right, correlations with Petropavlovsk and Klyuchi mean temperature of 19 months, from prior March–December through September of the current growth year are shown on the right. ° denotes a correlation significant at a 90% confidence level, whereas * denotes a correlation significant at the 99% confidence level.

3. Results

3.1. Stand Level Climate Signal

For the individual ring-width chronology, a strong positive correlation with mean monthly temperatures during summer (May or June through August) of the current growth year is observed in all the chronologies of both species (Figures 2 and 3). The three new larch records from an elevational transect on the Tobalchik Volcano show a generally improved correlation with summer temperature with increasing elevation (Figure 2). Lower and middle elevation UG and MK birch chronologies correlate negatively with May temperature (although not significant at the 90% confidence level; Figure 3). The northeastern birch, 50 km and NR sites (Table 1), have a consistent positive correlation with July temperature. In both regions, lower elevation birch chronologies generally show a weaker correlation to temperatures than the larch, as has been found elsewhere (Table 1, [11]).

Correlations with monthly precipitation records are not consistent at the northern sites for either larch or birch. However, in the south, positive correlation with March and May precipitation were found at all four birch sites (PRT, VV, UG and MK; Figure 4). In general, the higher elevation birch sites show a stronger relationship with spring precipitation than those at lower elevations.

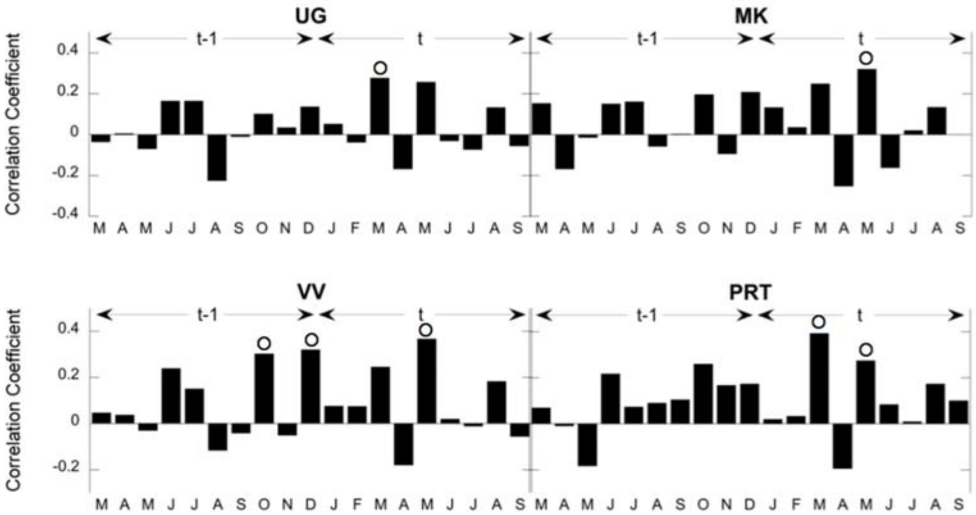
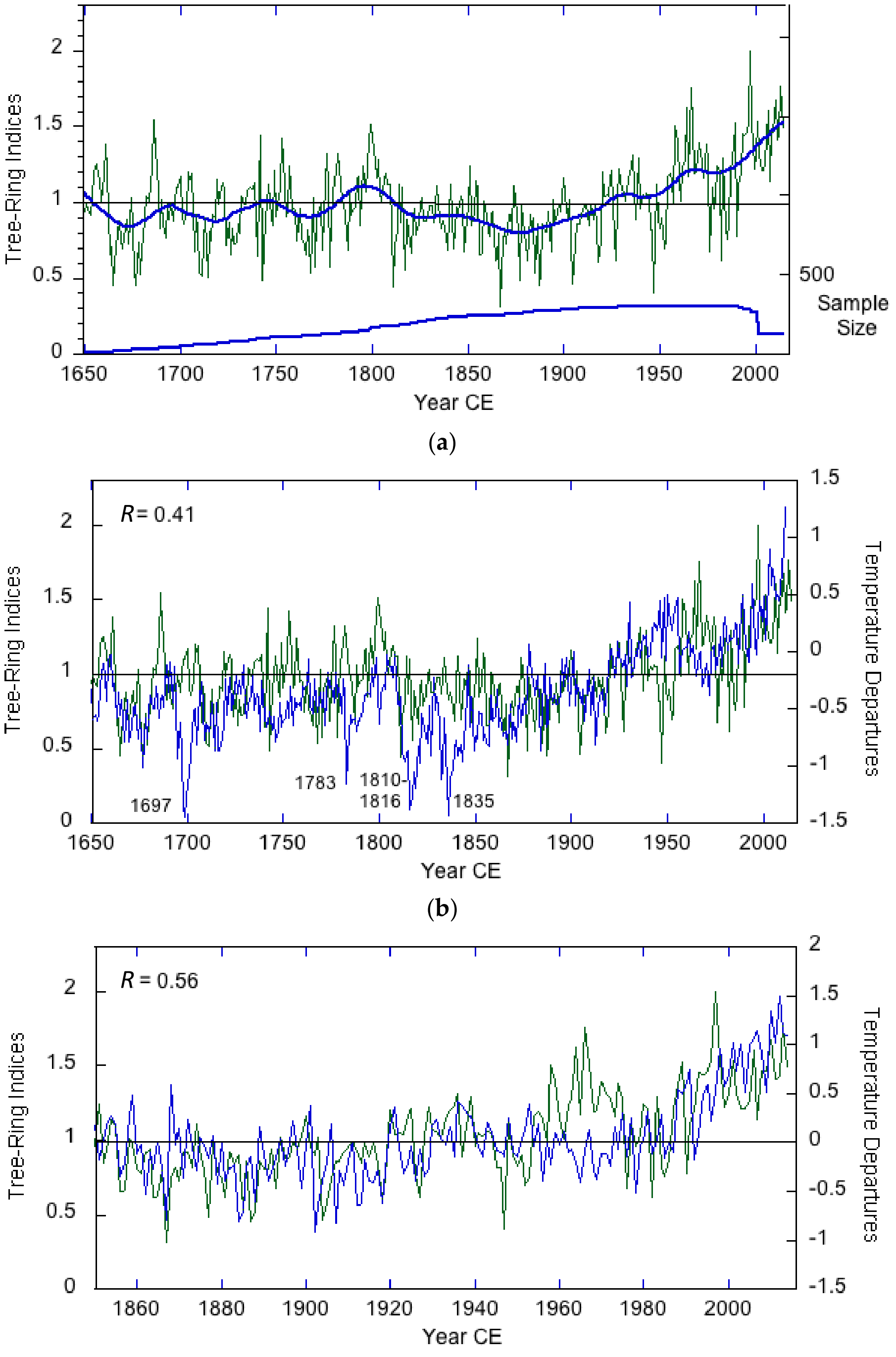


Figure 4. Correlations of the four southern Kamchatka birch ring width chronologies with monthly precipitation from Petropavlovsk-Kamchatsky. The circles denote those months that are significant at the 90% confidence level. In all cases, the period of overlap is 1941–2005 common era (CE).

To further analyze the temperature sensitivity and build on previous temperature reconstructions, we assembled the larch and birch series from our new collections with those of past studies for Kamchatka. For the Northeast sector, the 331 ring-width based larch chronology spans 1580 to 2014; the series has an EPS of 0.85 beginning in 1650 CE. This larch dataset is remarkably coherent given the diverse topography across Kamchatka, with a mean series intercorrelation of 0.62 and a mean sensitivity of 0.32 (a measure of interannual variability) (Figure 5a). For the birch, the 113 ring-width series from the four southern sites (including the Paratunka site [10]) were combined. The series intercorrelation is 0.53 with a mean sensitivity of 0.35 over the 1755–2014 CE common interval (Figure 6a).

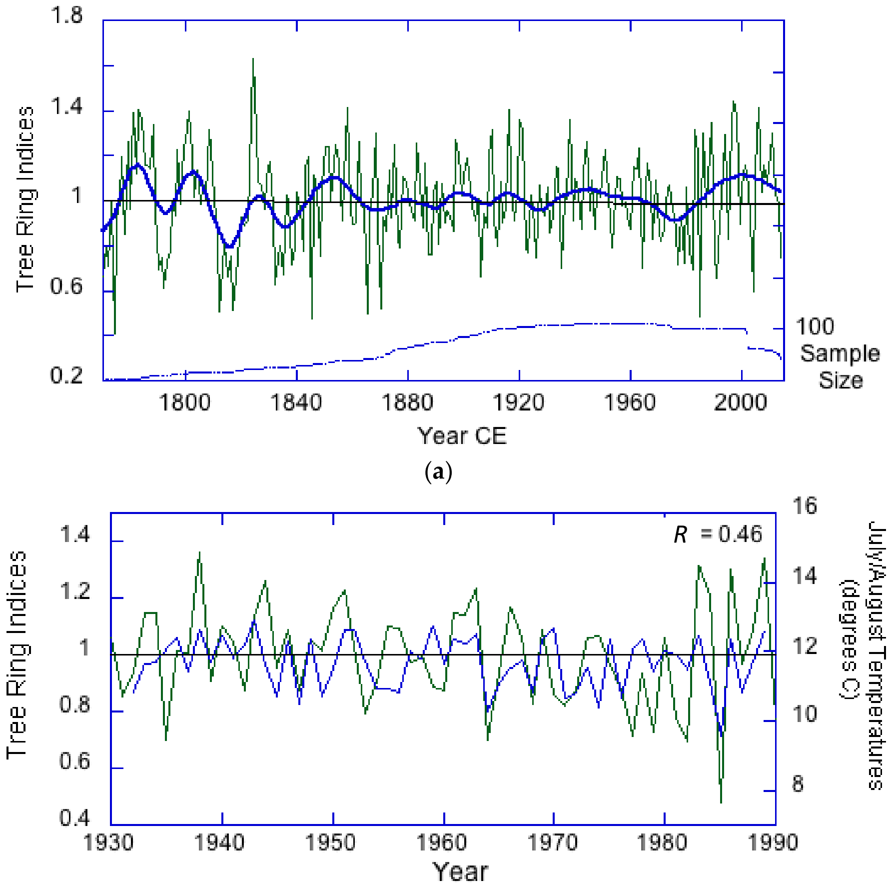


(**a**)

(**b**)

(**c**)

Figure 5. (**a**) Larch composite chronology (green, blue thick line shows values smoothed with a 6% weighted curve with Kaleidagraph) standardized using signal free regional curve standardization (RCS) and changing sample size over time (lower blue curve); (**b**) Larch composite chronology (green) compared with NTREND series (blue), which is composed of 54 Northern Hemispheric tree ring chronologies [20]. The correlation of larch with NTREND is 0.41 for 1670–2014. Major NH volcanic events are labeled on the NH record and note that the NH series deviates from the Kamchatka series; (**c**) Comparison of the larch ring-width series (green) with the Northern Hemisphere meteorological summer temperatures [20]. The two NH series are coherent with the larch ring-width series with respect to the low frequency variability. The records do diverge in the decades of the 1950s and 1960s, possibly due to wide scale disturbance and logging at the varied sites and a growth release during this time.



(**a**)

(**b**)

Figure 6. (**a**) Composite Kamchatka birch ring-width chronology. Blue line shows changing sample size; (**b**) Kamchatka birch chronology (green) plotted with July/August average temperatures from Ust-Kamchatsky ($R = 0.46$; $p > 0.001$).

3.2. Regional and Hemispheric Climate Signals

To further explore the regional climatic significance and dendroclimatic potential for forests in Kamchatka, we compared our regional larch RCS series and birch ring-widths with monthly climate records and with a tree-ring based Northern Hemisphere summer temperature reconstruction (NTREND) [20]. The larch composite, which is strongly correlated to local (Petropavlovsk-Kamchatsky) May–August temperatures over the 1909–2014 CE interval ($R = 0.46$; $N = 105$ years; not shown) is also strongly correlated with the May–August Northern Hemisphere instrumental temperature record ([20]; $R = 0.56$; $N = 164$ years; Figure 5c).

Comparison of the larch series with the tree-ring based NTREND [20] reconstructed temperature series shows good agreement ($R = 0.43$; 1670–2011CE; $N = 344$ years; Figure 5a,b) with the Kamchatka series, capturing the broad-scale features of low frequency summer warming for the Northern Hemisphere. Taken together, these results indicate that the Kamchatka larch is reflecting larger scale hemispheric temperature trends and is tracking the overall increase in summer temperature in the region that is well documented in the instrumental records and changes in the cryosphere [9].

Disagreement with the NTREND series primarily occurs during multi-year cooling forced by large-scale volcanic events (Figure 5b, [32]) that do not appear to have influenced summer temperatures in the interior of Kamchatka, but are well-expressed in the NTREND record (i.e., 1697, 1783, 1810–1816 and 1835 [32]; Figure 5b). The continual increase in ring-width in recent decades is commensurate with warming in the Northern Hemisphere and in Kamchatka ([9], Figure 5) and is not noticeably diverging from the warm conditions.

The temperature-sensitive composite birch chronology (Figure 6a) is also compared here with the coastal stations at nearby Petropavlovsk and Ust-Kamchatsky 450 km north of Petropavlovsk on the Pacific coast. A correlation of 0.48 with July/August temperatures (n = 59 years of observations from Ust-Kamchatky) is the strongest regional signal detected in the birch. Like the larch, the birch composite records the recent low frequency warming as seen in the more interior areas of Kamchatka and the NTREND series. Although the more coastal summer signal in the birch is not characterized by as strong of a low frequency rise as birch, the decades since the mid-1980s suggest the strongest summer warming for the past 200 years (Figure 6a). As noted above, some of the individual birch chronologies show a possible decline in ring-widths (Figure 3), however, the composite overall shows this sustained increase.

4. Discussion

All the tree-ring chronologies developed herein show positive correlations with current mean summer temperatures (Figures 2 and 3), indicating that temperatures during this season (May–August) have the strongest influence on radial growth of birch and larch trees in Kamchatka. Generally, correlations of mean monthly temperatures increase with increasing altitude in both the larch and birch series. These findings also follow the trends found in the northern interior Siberian larch studies that saw increased tree growth with warming summer temperatures [17,18]. Precipitation is not a significant influence on the northern study sites, but has significant positive correlations in March and May of the current growth year for southern sites.

The negative correlation of spring temperature with growth at the lower elevation sites in the southern birch series (UG, MK) suggests that warmer March–May temperatures may be unfavorable to growth as May and March are the driest months in southern Kamchatka and over the past 100 years, May has also warmed over 3.0 °C. This tendency may eventually negatively impact growth if summers continue to warm. Sano et al. [12] noted that their inland and coastal tree-ring reconstructions were out of phase with one another. We show that in more recent decades, our updated composite birch series is in step with birch growth and warming although further investigation is needed (Figure 6).

For the northeastern larch, the highest elevation chronology, TBT, is less strongly correlated with May temperature than the lower elevation MTB site (Figure 2). This pattern is also seen in the southern region where mean temperature at the VV birch site has the strongest correlation, instead of the highest elevation and better replicated PRT site in each summer month (Figure 3). This finding suggests that there may be an elevation where growth response to temperature is optimized somewhere between these elevations. Additional factors that could influence the varying climate response include differences in geography and climate at our sites compared with meteorological stations. Klyuchi is more inland compared with coastal Petropavlovsk-Kamchatsky and Ust-Kamchatsy (Figure 1), where the Pacific Ocean has a strong influence on temperature and precipitation. Both sites are at similar elevations with the coastal Petropavlovsk-Kamchatsky at 84 m and Klyuchi at 29 m a.s.l.

The low frequency climate signal in the larch record is broadly similar to that identified for the extratropical Northern Hemisphere (NTREND) [17] except for an interval in the late 1950s and 1960s. A possible explanation for this difference is that some of the series within our composite are from the area around Esso, a region impacted by forest fires in the late 1940s [33,34] and extensive construction of logging roads in the early 1960s. One or both of these factors may have forced a release in tree growth that may explain the disagreement in the larch series and the meteorological data. The larger deviations on the order of a year to several years occur during times when volcanic events [29] have forced cooling as exhibited in the NTREND record, but these events are not expressed in our composite larch series. Our updated larch ring-width series together with those from previous studies show that larch forests appear to be maintaining their growth in accordance with the strong climatic warming in the region, at least for the study sites. The birch record shows increased growth in response to the strong summer warming, however, it is unclear of the role that precipitation changes may have in controlling birch growth in southern Kamchatka.

5. Conclusions

In summary, trees from both the northeastern and southern regions have comparable responses to temperature. The tree ring chronologies described herein reveal that May–August summer temperatures are the main climatic influence on both birch and larch growth in Kamchatka, and that precipitation is important in March and May (Figure 4) for the southern birch chronologies. Sensitivity to climate increases with altitude and reveals a similar pattern to that seen at other northern sites [35] although trees lose their sensitivity at the very highest elevations [36]. In response to strong summer warming, both birch and larch are responding in phase. Despite inconsistencies between the larch composite chronology and the NTREND record, there is a strong low frequency warming signal in the larch series that reflects broad Northern Hemispheric trends. Future compilations of Northern Hemisphere temperature reconstructions of temperature should consider including this Kamchatka series to improve the coverage in the Asian Fareast.

Acknowledgments: This study was supported by NSF-ATM 115430, 1202218 and NSF-AGS-1502186. We thank Amanda Young for valuable feedback in this manuscript. LDEO contribution No. 8139.

Author Contributions: G.W., S.F., O.S., V.M. T.K. and R.D. designed and sampled for this study. C.D. and G.W. performed the analysis, and C.D., G.W., R.D. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sato, H.; Kobayashi, H.; Iwahana, G.; Ohta, T. Endurance of larch forest ecosystems in eastern Siberia under warming trends. *Ecol. Evol.* **2016**, *6*, 5690–5704. [CrossRef] [PubMed]
2. Tchebakova, N.M.; Parfenova, E.; Soja, A.J. The effects of climate, permafrost and fire on vegetation change in Siberia in a changing climate. *Environ. Res. Lett.* **2009**, *4*, 045013. [CrossRef]
3. Jones, V.; Solomina, O. The geography of Kamchatka. *Glob. Planet. Chang.* **2015**, *134*, 3–9. [CrossRef]
4. Eichhorn, M. Boreal forests of Kamchatka: Structure and composition. *Forests* **2010**, *1*, 154–196. [CrossRef]
5. Mock, C.J.; Bartlein, P.J.; Anderson, P.M. Atmospheric circulations patterns and climatic variations in Beringia. *Int. J. Climatol.* **1998**, *10*, 1085–1104. [CrossRef]
6. Braitseva, O.A.; Ponomareva, V.V.; Sulerzhitsky, L.D.; Melekestev, I.V.; Bailey, J. Holocene Key-Marker Tephra Layers in Kamchatka, Russia. *Quat. Res.* **1997**, *47*, 125–139. [CrossRef]
7. Wiles, G.C.; Solomina, O.; D'Arrigo, R.D.; Anchukaitis, K.; Gensiarovsky, Y.; Wiesenberg, N. Reconstructed Summer Temperatures over the Last 400 Years Based on larch ring widths: Sakhalin Island, Russian Far East. *Clim. Dyn.* **2015**, *45*, 397–405. [CrossRef]
8. D'Arrigo, R.; Wilson, R.; Wiles, G.; Anchukaitis, K.; Solomina, O.; Davi, N.; Deser, C.; Dolgova, E. Tree ring reconstructed temperature index for coastal northern Japan: Implications for western North Pacific variability. *Int. J. Climatol.* **2014**, *35*, 3713–3720. [CrossRef]
9. Gostev, M.; Wiles, G.; D'Arrigo, R.; Jacoby, G.; Khomentovsky, P. Early summer temperatures since 1670 A.D. for Central Kamchatka reconstructed based on a Siberian larch tree-ring width chronology. *Can. J. For. Res.* **1996**, *26*, 2048–2052. [CrossRef]
10. Solomina, O.; Wiles, G.; Shiraiwa, T.; D'Arrigo, R. Multiproxy records of climate variability for Kamchatka for the past 400 years. *Clim. Past Discuss.* **2006**, *2*, 1051–1073.
11. Sano, M.; Furuta, F.; Sweda, T. Summer temperature variations in southern Kamchatka as reconstructed from a 247-year tree-ring chronology of *Betula ermanii*. *J. For. Res.* **2010**, *15*, 234–240. [CrossRef]
12. Takahashi, K.; Homma, K.; Shiraiwa, T.; Vetrova, P.V.; Hara, T. Climatic Factors Affecting the Growth of Larix cajanderi in the Kamchatka Peninsula, Russia. *Eur. J. For. Res.* **2001**, *3*, 1–9.
13. Dolezal, J.; Ishii, H.; Takahaski, K.; Vetrova, V.P.; Homma, K.; Sumida, A.; Hara, T. Climatic factors affecting radial growth of *Betula ermanii* and *Betula platypylla*. Kamchatka. *Can. J. For. Res.* **2010**, *40*, 273–285. [CrossRef]
14. Newell, J. *The Russian Far East: A Reference Guide for Conservation and Development*, 2nd ed.; Daniel & Daniel Publishers Inc.: McKinleyville, CA, USA, 2004; pp. 341–373.

15. Solomina, O.; Pavlova, I.; Curtis, A.; Jacoby, G.; Ponomareva, V.; Pevzner, M. Constraining recent Shiveluch volcano eruptions (Kamchatka, Russia) by means of dendrochronology. *Nat. Hazards Earth Syst. Sci.* **2008**, *8*, 1083–1097. [CrossRef]
16. Sano, M.; Furuta, F.; Sweda, T. Tree-ring-width chronology of *Larix gmelinii* as an indicator of changes in early summer temperature in east-central Kamchatka. *J. For. Res.* **2009**, *14*, 147–154. [CrossRef]
17. Berner, L.T.; Beck, P.S.A.; Bunn, A.G.; Goetz, S.J. Plant response to climate change along the forest-tundra ecotone in northeastern Siberia. *Glob. Chang. Biol.* **2013**, *19*, 3449–3462. [CrossRef]
18. Lloyd, A.H.; Bunn, A.G.; Berner, L.T. A latitudinal gradient in tree growth response to climate warming in the Siberian taiga. *Glob. Chang. Biol.* **2011**, *17*, 1935–1945. [CrossRef]
19. Tei, S.; Sugimoto, A.; Yonenobu, H.; Matsuura, Y.; Osawa, A.; Sato, H.; Fujnuma, J.; Maximov, T. Tree-ring analysis and modeling approaches yield contrary response of circumboreal forest productivity to climate change. *Glob. Chang. Biol.* **2017**, 1–10. [CrossRef] [PubMed]
20. Wilson, R.; Anchukaitis, K.; Briffa, K.R.; Büntgen, U.; Cook, E.; D'Arrigo, R.; Davi, N.; Esper, J.; Frank, D.; Gunnarson, B.; et al. Last millennium northern hemisphere summer temperatures from tree rings: Part I: The long-term context. *Quat. Sci. Rev.* **2016**, *134*, 1–18. [CrossRef]
21. Holmes, R.L. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bull.* **1983**, *43*, 69–78.
22. Grissino-Mayer, H. Evaluating crossdating accuracy: A manual and tutorial for the computer program COFECHA. *Tree-Ring Res.* **2001**, *57*, 205–221.
23. Cook, E.R.; Holmes, R.L.; Adams, R.K.; Fritts, H.C. *Users Manual for Program ARSTAN: Tree-Ring Chronologies of Western North America: California, Eastern Oregon and Northern Great Basin*; Laboratory Tree Ring Research, The University of Arizona: Tucson, AZ, USA, 1986; pp. 50–65.
24. GISTEMP Team. GISS Surface Temperature Analysis (GISTEMP). NASA Goddard Institute for Space Studies. Available online: http://data.giss.nasa.gov/gistemp/ (accessed on 15 June 2015).
25. Hansen, J.; Ruedy, R.; Sato, M.; Lo, K. Global surface temperature change. *Rev. Geophys.* **2010**, *48*, 1–29. [CrossRef]
26. Solomina, O.; Institute of Geography RAS, Moscow, Russia. Personal communication, 2015.
27. Esper, J.; Cook, E.R.; Schweingruber, F.H. Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability. *Science* **2002**, *295*, 2250–2253. [CrossRef] [PubMed]
28. Melvin, T.M.; Briffa, K.R. CRUST: Software for the implementation of Regional Chronology Standardisation: Part 1. Signal-free RCS. *Dendrochronologia* **2014**, *32*, 7–20. [CrossRef]
29. Esper, J. Tests of the RCS method for preserving low-frequency variability in long tree-ring chronologies. *Tree-Ring Res.* **2003**, *59*, 81–98.
30. Wigley, T.M.L.; Briffa, K.R.; Jones, P.D. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *J. Clim. Appl. Meteorol.* **1984**, *23*, 201–213. [CrossRef]
31. Wilson, R.; Elling, W. Temporal instability in tree-growth/climate response in the Lower Bavarian Forest region: Implications for dendroclimatic reconstruction. *Trees* **2004**, *18*, 19–28. [CrossRef]
32. Sigl, M.; Winstrup, M.; McConnell, J.R.; Welten, K.C.; Plunkett, G.; Ludlow, F.; Buntgen, U.; Caffee, M.; Chellman, N.; Dahl-Jensen, D. Timing and climate forcing of volcanic eruptions for the past 2500 years. *Nature* **2015**, *523*, 543–549. [CrossRef] [PubMed]
33. Mosolov, V.I. Conservation of wild reindeer in Kamchatka. *Rangifer* **2000**, *20*, 95–98. [CrossRef]
34. Dolezal, J.; Ishii, H.; Vetrova, V.P.; Sumida, A.; Hara, T. Tree growth and competition in a Betula platyphylla-Larix cajanderi post-fire forest in central Kamchatka. *Ann. Bot.* **2004**, *94*, 333–343. [CrossRef]
35. Trouet, V.; Van Oldenborgh, G.H. KNMI Climate Explorer: A web-based research tool for high-resolution paleoclimatology. *Tree-Ring Res.* **2013**, *69*, 3–13. [CrossRef]
36. Jarvis, S.K.; Wiles, G.C.; Appleton, S.N.; D'Arrigo, R.D.; Lawson, D.E. A warming-induced biome shift detected in tree growth of Mountain Hemlock (*Tsuga mertensiana* (Bong.) Carrière) along the Gulf of Alaska. *Arct. Antarct. Alp. Res.* **2013**, *45*, 211–218. [CrossRef]