Postprint of Integrated Climate Records from the Northern Altai Mountains over the Past 2,000 Years

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Abstract

Based on a review of climate change research findings for the northern Altai Mountains over the past 2000 years, this study synthesizes the geographical consistency of climate information contained in the literature. With respect to temperature, temperature series reconstructed from lake cores, tree rings, and ice cores in the northern Altai Mountains have faithfully recorded major climate events in the Northern Hemisphere, including the Roman Warm Period (0–400 AD), Dark Ages Cold Period (400–600 AD), Medieval Warm Period (800–1200 AD), Little Ice Age (1400–1860 AD), and Modern Warm Period (since 1860 AD). Solar radiation variations controlled by solar activity represent the dominant factor driving temperature changes in the northern Altai Mountains over the past 2000 years, whereas the increase in atmospheric CO over the past 150 years constitutes the dominant factor for warming during the Modern Warm Period (since 1860 AD). Regarding precipitation, precipitation variation trends in the northern Altai Mountains over the past 2000 years reveal that high-precipitation periods occurred during 0–450 AD, 600–800 AD, 1050–1300 AD, and 1650–1860 AD, while low-precipitation periods occurred during 450–600 AD, 800–1050 AD, 1300–1650 AD, and 1860–2000 AD. Furthermore, the combination of temperature and precipitation in the northern Altai Mountains over the past 2000 years does not support the so-called “warm-dry and cold-wet” hydrothermal configuration pattern.

Full Text

Synthesized Climate Change in the North Altay Mountains Over the Past 2000 Years

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Abstract: This study first reviews the research achievements on climate change in the North Altay Mountains over the past 2000 years, and then summarizes the geographical consistency of climate information contained in these records. Multi-proxy evidence (lake cores, tree rings, and ice cores) reveals five important climatic events in the Northern Hemisphere, including the Roman Optimum (0–400 AD), Dark Age Cold Period (400–600 AD), Medieval Warm Period (800–1200 AD), Little Ice Age (1400–1860 AD), and the recent warming period (since 1860 AD). These climatic events were mainly modulated by solar activity-dominated solar radiation variations during the past 2000 years, while recent warming since 1860 AD has been largely attributable to increased CO concentration over the past 150 years. Precipitation history in the North Altay Mountains over the past 2000 years indicates that periods including 0–450, 600–800, 1050–1300, and 1650–1860 AD were characterized by high precipitation, while those including 450–600, 800–1050, 1300–1650, and 1860–2000 AD featured low precipitation. Additionally, the combination of temperature and precipitation patterns in the North Altay Mountains over the past 2000 years does not support the "cold-wet and warm-dry" hydrothermal configuration typical of arid zones in Central Asia.

Keywords: climate change; tree ring; lake core; ice core; Altay Mountains

2. Data and Methods

2.1 Lake Core Records

Shira Lake: Shira Lake has a surface area of 35.9 km² and maximum depth of 24 m. Its primary water sources are the Son River (50%) and precipitation (17%). The multi-year average precipitation is 300 mm, with mean July temperature of 18°C and mean January temperature of -20°C [Figure 1: see original paper]. The lake' s sedimentary records show distinct variations in carbonate mineralization over the past 2500 years [Figure 3: see original paper]. Pollen analysis reveals that during 0–1040 years, arboreal taxa (Betula, Pinus) dominated, indicating a warm and humid climate. Kalugin et al. [19] reconstructed quantitative precipitation and lake level changes in the Shira Lake region, identifying wet periods at 0–450, 600–800, 1050–1300, and 1650–1860 years, and dry periods at 450–600, 800–1050, 1300–1650, and 1860–2000 years [Figure 3a: see original paper]. Darin et al. [18] established a quantitative precipitation reconstruction model: T = 0.1633×D(c) - 0.151×( ) - 1.3817, with a resolution

of 4000 years. Rudaya et al. [23] reconstructed precipitation changes over the past 4500 years.

Teletskoye Lake: Located in the Russian Altay, Teletskoye Lake has an elevation of 434 m. The sedimentary records show significant environmental changes over the past 2000 years .

2.2 Ice Core Records

Ice cores from Belukha (49°48 26 N, 86°34 43 E, elevation 4062 m) and Tsambagarav (48°39 N, 90°50 E) glaciers provide high-resolution climate records . Eichler et al. [31] reconstructed temperature variations over the past 1250 years from the Belukha ice core. The ^{1} O record shows cold periods at 1300, 1450–1550, 1700, 1840, and 1930 years, corresponding to solar minima (Wolf, Spörer, Maunder, Dalton, Gleissberg) [Figure 7b: see original paper]. Since 1850, the ^{1} O record indicates a warming trend of (2.5±1.7)°C [31, 40]. Aizen et al. [32] reconstructed temperature changes over the past 2000 years from the Belukha ice core.

2.3 Tree Ring Records

Tree-ring chronologies from the North Altay Mountains span the past 2000 years [Figure 5: see original paper]. Myglan et al. [26, 27] developed a 2367-year tree-ring chronology for the Altai-Sayan region (Mongun-Taiga Massif). Sidorova et al. [28, 29] used multi-proxy approaches to reconstruct July–August temperatures over the past 2000 years [Figure 6a: see original paper]. The records show a cooling trend from 1830–1880, with the warmest decade in the 1930s. Shah et al. [30] reconstructed August–July precipitation from tree rings in the forest-steppe zone of Central Siberia.

3. Temperature Changes Over the Past 2000 Years

Temperature reconstructions from lake cores, ice cores, and tree rings reveal five distinct climatic periods:

1. **Roman Optimum (0–400 AD):** Warm period recorded in Shira Lake pollen data [Figure 3a: see original paper] and Teletskoye Lake sediments.
2. **Dark Age Cold Period (400–600 AD):** Cold period documented in multiple proxies.
3. **Medieval Warm Period (800–1200 AD):** Warm period evident in tree-ring records [Figure 5: see original paper] and ice core data.
4. **Little Ice Age (1400–1860 AD):** Cold period with four major cold phases: 1550–1600, 1600–1670, 1778–1900, and 1900–2000 years [Figure 4: see original paper]. The coldest period occurred during 1612–1630 years.
5. **Recent Warming (since 1860 AD):** Significant warming trend, particularly after 1930, with accelerated warming since 1950 [Figure 7: see original paper].

The temperature variability correlates strongly with solar activity [FIGURE:8f, 8g]. The Belukha ice core ^{1}O record shows temperature lags solar forcing by several years [31].

4. Precipitation Changes Over the Past 2000 Years

Precipitation reconstructions show alternating wet and dry periods:

High precipitation periods: 0–450, 600–800, 1050–1300, and 1650–1860 AD
Low precipitation periods: 450–600, 800–1050, 1300–1650, and 1860–2000 AD

Tree-ring precipitation records from the past 200 years show high interannual variability [Figure 6: see original paper]. The 1830s–1880s were relatively dry, while the 1930s–1990s showed increased precipitation [28, 29]. Since 2000, precipitation has decreased again [30].

The 2000-year precipitation record from Shira Lake [Figure 8a: see original paper] and Teletskoye Lake [Figure 8c: see original paper] demonstrates that the "cold-wet and warm-dry" pattern does not consistently apply to the North Altay region.

5. Comparison and Discussion

Multi-proxy comparisons reveal coherent climate signals across the North Altay Mountains [Figure 8: see original paper]. The synchronization of temperature and precipitation changes suggests common forcing mechanisms:

1. **Solar forcing:** Dominant driver of pre-industrial climate variability, with solar minima corresponding to cold periods [Figure 8f: see original paper].
2. **CO forcing:** The recent warming since 1860 AD, particularly after 1950, aligns with increased atmospheric CO concentrations [Figure 8g: see original paper].
3. **Regional patterns:** The North Altay Mountains show both similarities and differences with broader Central Asian climate patterns. The region experienced the major Northern Hemisphere climatic events but with local variations in timing and magnitude.

The combination of temperature and precipitation data does not support a simple "cold-wet and warm-dry" configuration for the North Altay Mountains, challenging the prevailing paradigm for Central Asian arid zones.

6. Conclusions

1. The North Altay Mountains experienced five major climatic periods over the past 2000 years: Roman Optimum, Dark Age Cold Period, Medieval Warm Period, Little Ice Age, and recent warming.
2. Solar activity was the primary driver of climate variability before 1860 AD, while CO increase has dominated recent warming.

3. Precipitation showed multi-centennial oscillations, with wet periods at 0–450, 600–800, 1050–1300, and 1650–1860 AD, and dry periods at 450–600, 800–1050, 1300–1650, and 1860–2000 AD.
4. The temperature-precipitation relationship does not follow the simple "cold-wet and warm-dry" pattern, indicating complex hydroclimatic dynamics in the region.

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Note: Figure translations are in progress. See original paper for figures.