

## Disappearing Evidence: the Need for a Global Paleoclimate Observing System

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A major obstacle standing in the way of producing reliable predictions of climate change and its ecological impacts is a lack of data on timescales longer than the short instrumental record. We will need to continuously operate recently initiated international global climate observation programmes for at least 50 years before they begin to provide relevant information. Natural archives of past climate variability can provide the same information now. Unfortunately, some of the most valuable paleoclimate archives are being rapidly altered, largely due to human influences. We cannot afford such an irreversible loss. The IGBP-Past Global Changes project therefore calls for scientists and institutional partners to help establish immediately a coordinated international Global Paleoclimate Observing System (GPOS) to complement the recently established Global Climate, Terrestrial and Ocean Observing System (GCOS, GTOS, GOOS) that focus only on contemporary observations. There is no time to lose.

Warming has been measured over most parts of the globe during the late 20<sup>th</sup> century. But instrumental data provide only a limited perspective on this climate change. Because instrumental measurements cover mainly the period of industrialization, they offer little information with which to distinguish between natural and anthropogenic causes of the observed warming. Paleoclimate archives can provide such information by extending the climate record over decadal to millennial time scales. Furthermore, paleodata can be used to predict future ecosystem changes associated with climate change, based on ecosystem responses to climate changes in the past. Climate-related variables such as temperature, salinity, pH, oxygen level, CO<sub>2</sub> concentration, moisture balance and circulation strength can be quantitatively reconstructed using various biological indicators (pollen, chironomids, diatoms, cladocerans), isotopes, and

other proxy measurements in lake and ocean sediments, corals, speleothems, polar ice, tree rings, mountain glaciers and other paleoclimate archives. Although tapping the information contained in these paleoclimate archives has an enormous potential to contribute

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to our understanding of linkages between ecosystems and climate, recent anthropogenic factors are leading to the destruction of many of these unique sources of valuable information. Therefore, we call for an internationally coordinated effort, GPOS, designed to rescue endangered natural archives of past environmental variability on socially-relevant time scales, and expedite large-scale observational and experimental campaigns to investigate the mechanisms

producing natural archives.

A first example of destruction of paleoclimate archives is the ongoing widespread bleaching of corals. Coral measurements (Figure 1) have been used successfully to reconstruct sea surface temperature and salinity and even the surface circulation of the tropical oceans for the past several hundred years. They have provided isolated windows during the more distant past, often with a temporal resolution of only a few weeks [5, 15]. Furthermore, corals have recorded past changes in the frequency and magnitude of El Niño events with direct consequences for predictability. Coral based reconstructions, for example, indicate a shift from primarily decadal El Niño Southern Oscillation variability in the 1800's to the interannual variability of the last century [16]. Long coral based records also help to quantify the significance of the 1976 El Niño Southern Oscillation shift by providing a longer term record.

Large living corals (>100-200 years old) suitable for climate reconstruction purposes are relatively rare in most reef areas of the world. Unfortunately, a significant number of these corals have been killed in recent years, and the outlook for many others may be bleak (Figure 2). Corals are under threat from localized stresses related to coastal development and population pressure. Dynamite and cyanide fishing, dredging for engineering works, nutrient overloading, the disruption of grazing fish populations (which allows algal overgrowth), coastal pollution, and unregulated development all contribute to coral mortality, particularly in populated regions of the tropics.

In addition to these local processes, there is a widespread mortality of corals due to coral 'bleaching' consequent on exceptional 'warm' climatic extremes. These extremes are

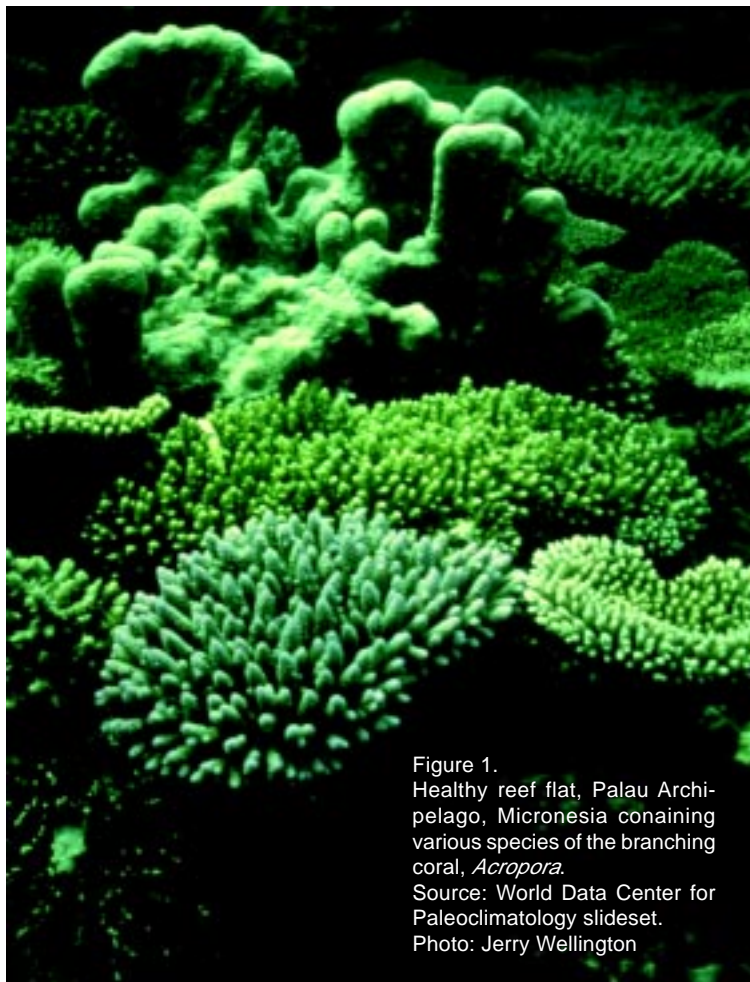


Figure 1.  
Healthy reef flat, Palau Archipelago, Micronesia containing various species of the branching coral, *Acropora*.  
Source: World Data Center for Paleoclimatology slideset.  
Photo: Jerry Wellington

ated with the 1982/83 and 1997/98 El Niño events caused mass mortality of corals in large areas of the equatorial Pacific, and western Indian Ocean. Even the corals that recover from bleaching may have reduced fecundity and reduced tolerance to future stress [12]. The death of corals being used to reconstruct paleoclimate is not a theoretical problem – it is real. Once the corals die, the potential for climate reconstruction from the skeletons is severely reduced. The dead coral skeletons are prone to rapid physical and biological erosion, and the absolute chronology (a key factor in identifying leads and lags in the climate system) is lost. As one example, the 1982/83 El Niño caused coral mortality throughout the Galapagos. Some

often associated with El Niño events, and have been observed in all the world's tropical oceans. Coral 'bleaching' describes the loss of color of reef building corals due to the expulsion of symbiotic algae (or loss of their photosynthetic pigments) from the coral tissue. The most common cause of coral bleaching is elevated sea surface temperature. Specifically, bleaching often occurs when local sea surface temperatures exceed their usual warm season maximum by >1-2 °C for periods exceeding a few weeks. In some cases, other environmental factors such as low salinity or increased exposure to solar radiation are also implicated. Once bleached, the corals have lost a major source of their nutritional energy (which comes from their algal symbionts), have very limited ability to calcify, and, if the condition persists, the corals die. Major bleaching events associ-



Figure 2.  
Erosion of *Pavona* coral on Saboga Island, Panama. This erosion damage is caused by sea urchins which scrape away coral as they graze on algae superimposed on a coral already partially killed by warm conditions during the 1982-83 El Niño.  
Source: World Data Center for Paleoclimatology slideset,  
Photo: Mark Eakin.



scientists predict a global demise of coral reefs within the next few decades due to global warming [7]. An overview of areas thought to be susceptible to bleaching can be found at: <http://psbsgi1.nesdis.noaa.gov:8080/PSB/EPS/SST/climohot.html>.

In addition to bleaching, recent studies indicate that corals and other calcifying marine organisms are under geochemical threat from rising CO<sub>2</sub> concentrations. As atmospheric CO<sub>2</sub> increases, oceanic CO<sub>2</sub> rises and carbonate concentration drops, making the oceans more acidic and removing the CO<sub>3</sub><sup>2-</sup> needed for skeletal formation. Carbonate supersaturation is maintained, but even a drop in the supersaturation level appears to influence the ability of corals and other organisms to form calcium carbonate skeletons. [8; 10; 9]. The combination of localized stresses with background warming and increasing CO<sub>2</sub> means that corals are experiencing multiple stresses on many fronts - physical, ecological, geochemical - and are

increasingly vulnerable to mass mortality.

Coral archives are not the only ones under severe threat: alpine glaciers in both the tropics and temperate latitudes are melting. Ice cores from such glaciers have been used to reconstruct temperature, precipitation and atmospheric dust levels [13], and they provide information about climate dynamics, including changes in the strength of the Asian monsoon [14] and El Niño Southern Oscillation [6; 11]. All mountain glaciers in tropical and temperate latitudes, with the exception of those in Scandinavia, are now rapidly retreating. As shown in figure 3, the volume of the summit glacier on Kilimanjaro (figure 4) has decreased by 81% between 1912 and 2000. If this trend continues, there will soon be no paleoclimatic information stored in ice at high altitude, low-latitude sites. The only information from the Kilimanjaro ice will be what is left of the cores extracted last year by Lonnie Thompson and

his group and stored in freezers at Ohio State University. Given the critical importance of the low latitude regions as drivers of climate on Earth, this loss will irretrievably hobble our ability to use the past to predict the future. For an extensive overview of the status of glaciers around the world, see the world glacier monitoring service web site (<http://www.geo.unizh.ch/wgms/>).

Until the last few years, the use of tree rings as records of past environmental variability has been limited, almost entirely, to the middle and high latitudes. Real progress is being made with developing methods for decoding tropical tree rings, and these records promise to yield vital information on many aspects of tropical environments, from the Asian monsoon and El Niño to the factors controlling the storage of carbon in tropical forests. The use of tree rings from tropical trees is now moving into the phase where continental-scale networks of collections must be made and analyzed to extract vital environmental information. For example, teak trees, in a huge arc from India through Myanmar, Thailand, Indonesia and the Philippines, have annual rings that can be used as records of climate, especially conditions at crucial times of year, the dry season and the transition to the rainy season. At the same time as this progress has been made, massive felling of the commercially valuable timber of old-growth teak has been going on, raising the possibility that many of the old trees, containing the most valuable information, will already have been fed to the sawmills [4].

Though their existence may not be directly under threat, the interpretation of other paleodata may also be increasingly complicated by the activities of humans. The relationships between tree-ring properties and regional climate parameters, for example, are widely used for reconstruct-

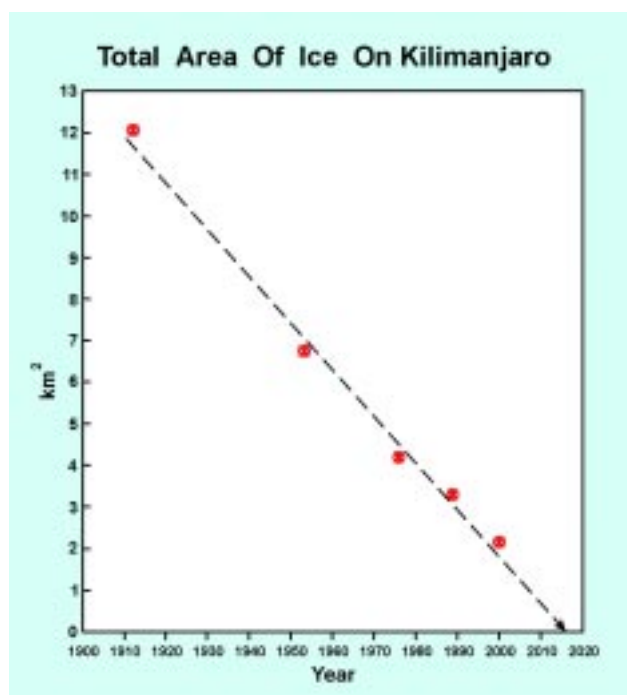


Figure 3. Total areal cover of the ice cap on Kilimanjaro from 1912 to present. Should the measured rate of retreat continue unchanged the ice cap will have vanished by around 2015. Source: Lonnie Thompson, unpublished data.

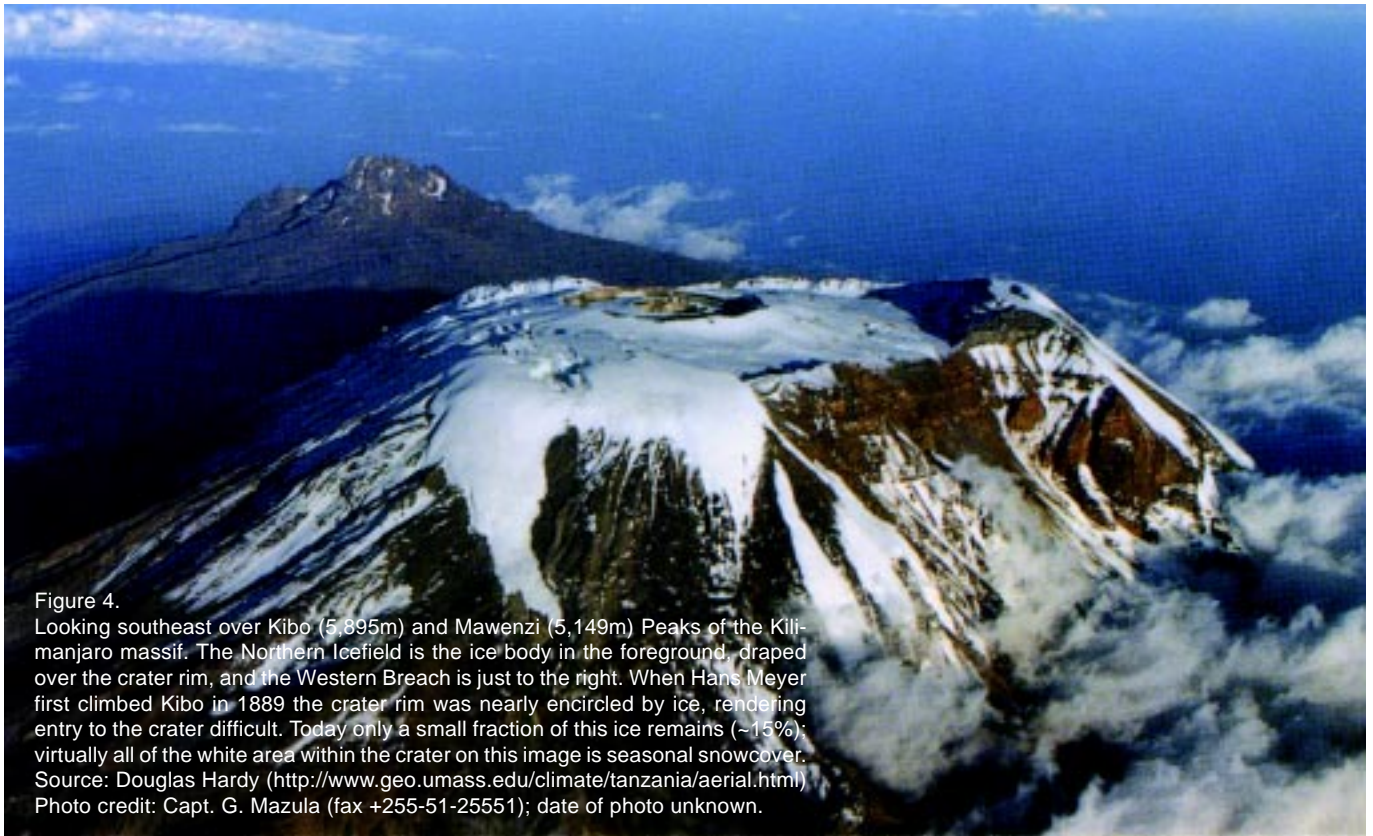


Figure 4. Looking southeast over Kibo (5,895m) and Mawenzi (5,149m) Peaks of the Kilimanjaro massif. The Northern Icefield is the ice body in the foreground, draped over the crater rim, and the Western Breach is just to the right. When Hans Meyer first climbed Kibo in 1889 the crater rim was nearly encircled by ice, rendering entry to the crater difficult. Today only a small fraction of this ice remains (~15%); virtually all of the white area within the crater on this image is seasonal snowcover. Source: Douglas Hardy (<http://www.geo.umass.edu/climate/tanzania/aerial.html>) Photo credit: Capt. G. Mazula (fax +255-51-25551); date of photo unknown.

ing past climate. At high northern latitudes, tree-ring densities show a strong correlation with summer temperature. Transfer function based estimates of temperature from trees in this region are accurate recorders of large-scale temperature on short (interannual and decadal) and long (multidecadal) timescales: demonstrably during the early part of the twentieth century

During the second half of the twentieth century, tree density averaged around the Northern Hemisphere, still mirrors the year-to-year change in hemispheric temperatures accurately, but the density and temperature trends have increasingly diverged [3]. The evidence on more local geographic scales is varied, but, at least in subarctic Eurasia, might be linked to an increase in winter precipitation that delays the onset of tree growth [17]. Other speculative possibilities include some link with a general fertilization effect seen in other tree-growth parameters, possibly due to high atmospheric CO<sub>2</sub> concentrations or nitrogen-bearing precipitation, or the

effects of acid rain or enhanced ultraviolet radiation [2].

Whatever the cause, this phenomenon points toward the need for more integrated process studies that involve the use of multiple archives, observations, models and experiments capable of providing an understanding of the time-dependent interrelationships between different biological and physical processes. These studies may require a major effort to update many important paleo climate and environmental archives. During recent decades,

the combination of different environmental changes, many the result of human activities, may well be complex beyond precedent.

Similar changes have occurred in chironomid communities in the lakes of northern Sweden. Chironomid species assemblages recorded in lake sediments are used to make quantitative reconstruction of mean July air temperature. This method has been shown to reconstruct lake temperatures accurately during the last Qua-

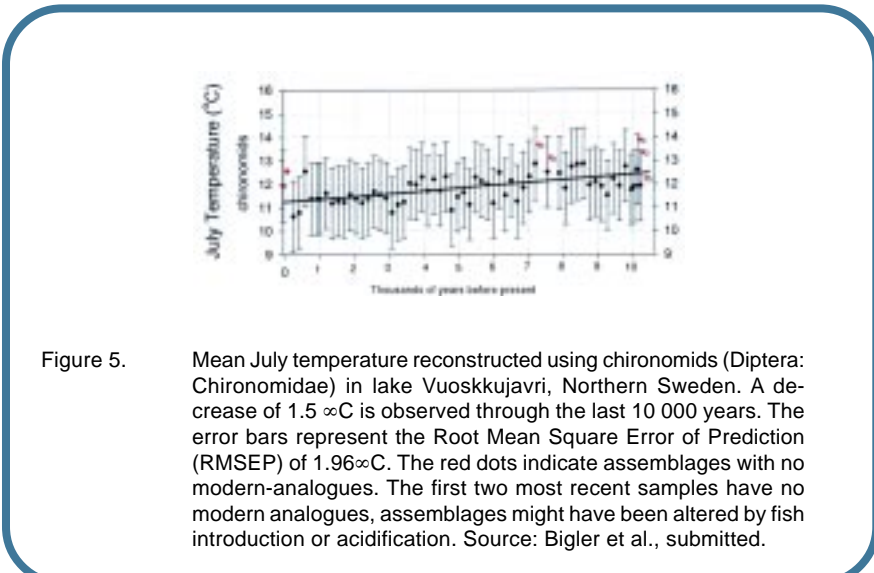


Figure 5. Mean July temperature reconstructed using chironomids (Diptera: Chironomidae) in lake Vuoskkujavri, Northern Sweden. A decrease of 1.5 °C is observed through the last 10 000 years. The error bars represent the Root Mean Square Error of Prediction (RMSEP) of 1.96°C. The red dots indicate assemblages with no modern-analogues. The first two most recent samples have no modern analogues, assemblages might have been altered by fish introduction or acidification. Source: Bigler et al., submitted.

ternary period. However, in some lakes there is no modern analogue for the species assemblages in the most recent sediments [1]. The absence of correspondence in modern assemblages of this lake, compared to assemblages in a 100-lake training set in the area, indicates that factors such as fish introduction or acidification has modified the “natural” assemblages of this lake. For many paleoreconstructions, as in both the tree ring and chironomid examples above, quantification of past temperature changes is based on the concept of a transfer function. When human influences become so strong that the organisms used for such reconstruction are no longer reacting directly to climate but responding instead to other anthropogenic factors, these transfer functions cannot be applied. By changing biological

assemblages or biological responses of organisms, anthropogenic factors can lead to potential misinterpretation of ecological responses to future climate change scenarios.

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## References

1. Bigler, C., Larocque, I., Peglar, S., Birks, H.J.B., Hall, R.I. (Submitted). “Holocene environmental change: A quantitative multi-proxy study from a small lake in Abisko, Swedish Lapland.” *The Holocene*.
2. Briffa, K. R. (2000). “Annual climate variability in the Holocene: interpreting the message of ancient trees.” *Quaternary Science Reviews* 19: 87-105.
3. Briffa, K. R., F. H. Schweingruber, P. D. Jones, T. J. Osborn, S. G. Shiyatov and E. A. Vaganov (1998). “Reduced sensitivity of recent tree-growth to temperature at high northern latitudes.” *Nature* 391: 678-682.
4. D’Arrigo, R.D. and Jacoby, G.C. (1994). “On the need to rescue teak wood from Southeast Asia for dendroclimatic study.” PAGES Newsletter 2(3) November 1994.
5. Gagan, M. K., L. K. Ayliffe, J. W. Beck, J. E. Cole, E. R. M. Druffel, R. B. Dunbar and D. P. Schrag (2000). “New views of tropical paleoclimates from corals.” *Quaternary Science Reviews* 19: 45-64.
6. Henderson, K. A., L. G. Thompson and P. Lin (1999). “Recording of El Niño in ice core d<sup>18</sup>O records from Nevado Huascaran, Peru.” *Journal of Geophysical Research* 104: 31053-31065.
7. Hoegh-Guldberg, O. (1999). “Climate Change, coral bleaching and the future of the world’s coral reefs.” *Marine and Fresh Water Research* 50(8): 839-866.
8. Kleypas, J. A., R. W. Buddemeier, D. Archer, J. P. Gattuso, B. N. Opdyke, C. Langdon and M. Frankignoulle (1999). “Geochemical consequences of increased atmospheric CO<sub>2</sub> on corals and coral reefs.” *Science* 284: 118-120.
9. Langdon, C., T. Takahashi, C. Sweeney, D. Chipman, J. Goddard, F. Marubini, H. Aceves, H. Barnett and M. Atkinson (2000). “Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef.” *Global Biogeochemical Cycles* 14: 639-954.
10. Marubini, F. and M. Atkinson (1999). “Effect of lowered pH and elevated nitrate on coral calcification.” *Marine Ecology Progress Series* 188: 117-121.
11. Moore, G. W. K., G. Holdsworth and K. Alverson (in press). “Extra-Tropical Response to ENSO 1736-1985 As Expressed In An Ice Core From The Saint Elias Mountain Range In North-western North America.” *Geophysical Research Letters*.
12. Normile, D. (2000). “Ninth International coral reef symposium: Reef migrations, bleaching effects stir the air in Bali.” *Science* 290: 1282-1283.
13. Thompson, L. G., Davies, M.E., Mosley-Thompson, E., Sowers, T.A., Henderson, K.A., Zagorinov, V.S., Lin, P.-N., Mikhalenko, V.N., Campen, R.K., Bolzan, J.F., Cole-Dai, J., Francou, B. (1998). “A 25,000-year tropical climate history from Bolivian ice cores.” *Science* 282: 1858-1864.
14. Thompson, L. G., T. Yao, E. Mosley-Thompson, M. E. Davis, K. A. Henderson and P.-N. Lin (2000). “A High-Resolution Millennial Record of the South Asian Monsoon from Himalayan Ice Cores.” *Science* 289(5486): 1916-1919.
15. Tudhope, A. W., C. P. Chilcott, M. T. McCulloch, E. R. Cook, J. Chappell, R. M. Ellam, D. W. Lea, J. M. Lough and G. B. Shimmield (2001). “Variability in the El Niño-Southern Oscillation Through a Glacial-Interglacial Cycle.” *Science* 291 (5508): 1511-1517.
16. Urban, F. E., J. E. Cole and J. T. Overpeck (2000). “Influence of mean climate change on climate variability from a 155-year tropical Pacific coral record.” *Nature* 407: 989-993.
17. Vaganov, E. A., M. K. Hughes, A. V. Kidyanov, F. H. Schweingruber and P. P. Silkin (1999). “Influence of snowfall and melt timing on tree growth in subarctic Eurasia.” *Nature* 400: 149-151.