The science of climate change

Andrew Weaver
School of Earth and Ocean Sciences, University of Victoria, BC

Central to the findings of the Intergovernmental Panel on Climate Change (IPCC) third assessment report, released in Shanghai in January 2001, was the statement: "There is now new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." This represents a significant strengthening of the analogous statement issued by the IPCC in 1996: "The balance of evidence suggests a discernible human influence on global climate" In this talk the scientific evidence leading up to these IPCC statements is reviewed. A historical perspective of the Earth's climate over the last 400,000 years is presented, as is the science of global warming over the last 200 years. The range of projections of climate change over the next century is also summarized giving particular emphasis to projections concerning Canada. The issue of public confusion arising from the media portrayal of the science and its entry into the political arena discussed. Finally, recent research is presented that demonstrates that the area burned by forest fires in Canada has increased over the past four decades, at the same time as summer season temperatures have warmed. Output from a coupled climate model is used to demonstrate that this warming is attributable to human emissions of greenhouse gases and sulfate aerosol. We further show that human-induced climate change has had a detectable influence on the area burned by forest fires in Canada over recent decades.

Impacts of past climate change on species distributions of woody plants in North America

Steven Jackson
University of Wyoming

The modern distributions and genetic structure of North American tree species represent, in part, legacies of climate changes of the past 25,000 years and more. Development of extensive networks of pollen and plant-macrofossil records from lakes, wetlands, and woodrat-middens across North America are revealing the magnitude and complexity of climate-change effects. Climate changes since the last glacial maximum have affected the geographic distributions of every tree species on the continent. However, not all species have been affected in the same way. In fact, a broad spectrum of responses is observed in the fossil record. Species responses have ranged from complete geographic displacements to relatively minor shifts along local habitat gradients. Many species that were widespread and dominant during the last glacial maximum continue to be widespread and dominant today, although in different locations. However, other dominant, widespread species of the past are now highly restricted (and in one case, extinct), while several minor glacial-age species have expanded to become dominant over wide regions today. Several species, rare today and rare during the last glacial maximum, were regionally dominant during the late-glacial transition. Some species have even contracted their ranges southward since the last glacial period. The diversity of responses observed in the fossil record can be explained by the diversity of ecological niches represented by tree species, together with the complex and multivariate nature of climate change. Many of the unexpected distributional changes (e.g., southward migration during a glacial-to-interglacial transition) and peculiar species assemblages (e.g., forests of spruce, elm, ash, and hornbeam) observed in the fossil record are attributable to past climates that have no counterparts in the modern world. A major challenge for the future is to determine whether we can develop capability to predict responses to ongoing and future climate change. This task is not as straightforward as it might seem; future climates are likely to have no modern analogs, and may be as different from those of the 20th Century as were climates of 11,000 years ago. It is thus essential to integrate our understanding of past responses from the fossil record with knowledge of modern ecology and genetics to identify the critical climate controls of abundance and distribution.

Climate change; impacts and adaptations for forestry

Dr. Dave Spittlehouse
British Columbia Ministry of Forests, Victoria, British Columbia

Adaptation to climate change
Climate change adaptation strategies should be based on the application of vulnerability assessments or risk management concepts. A planning framework for facilitating adaptation in forestry must address biophysical and socio-economic impacts and will include policy and institutional considerations. The framework requires us to analyse the situation and assess current and future vulnerabilities of forests to climate change. We can then develop risk management strategies that include actions needed now as well as future actions required when climate change has an unacceptable impact on forests. Adaptation needs to reduce current vulnerability, speed recovery after disturbance, and reduce vulnerability to further climate change. The adaptation plan should include monitoring the state of the forest to detect change. An example of using this framework in forest management to adapt to change will be presented. Many forest ecosystems and species will have to adapt autonomously because management can only influence the timing and direction of forest adaptation at selected locations. In general, society will have to adjust to however forests adapt.

Impacts of climate change on populations and species distributions

Dr. Isabelle Chuine
Centre for Evolution and Functional Ecology, France

Concern about climate change is increasing because ecological as well as socio-economic impacts are more and more perceptible. Reported ecological consequences of global warming mainly concern changes in the phenology and the distribution of the flora and fauna (see for Review Parmesan and Yohe 2003). In this talk I will present advances in species distribution modelling and provide predictions about species distribution changes for a couple of forest trees and compare them to past changes.

Biome, species, and population responses to climate and to climate-change in Siberia and western North America

Gerald Rehfeldt, USDA, Forest Service
Nadezda Tchebakova, and Elena Parfenova, Russian Academy of Science

Our work is governed by the principle that climate is the primary factor controlling the distribution of plants. This climate-plant relationship was recognized long ago (e. g., Plesheev in 1797 and Humboldt in 1807) but even today is poorly understood (Woodward 1987). As an aid, we use the thin plate splines of Hutchinson to develop climate surfaces from which the effects climate and climate-change on the distribution of biomes, species, or climatypes (climatic ecotypes) can be mapped.

Bioclimatic models relating the distribution of vegetation zones to climate have been developed for central Siberia. According to these models, the greenhouse gas scenario of the Hadley Centre should result ultimately in a complete redistribution of vegetation zones over the plains and tablelands of Siberia by the end of this century. Northern vegetation types (tundra, forest-tundra, and northern taiga) which are dominant in the contemporary climate should be replaced by southern types such as the southern taiga and subtaiga, forest-steppe, and steppe move northward. Of these southern types, neither of the latter two currently occur north of 56°. Dark-needled taiga concomitantly should move eastwards following the retreat of permafrost.

Species distributions also have been mapped for *Pinus sylvestris* and *Larix* spp. of Siberia using the three-variate climatic envelope of Box (1999) and for *Picea engelmannii* of western USA using 17 climate variables and a combination of the climatic envelope and a discriminant function of 10 species. Once mapped, distributions can be recast according to climate-change scenarios of the GCM's. For *P. engelmannii* in the region south of 51°N, the 2100 distribution is projected to be 12% of the contemporary. In Siberia, the areal extent of lands potentially suitable for *P. sylvestris* and *Larix* spp. should increase markedly by 2100, although actual distributions will depend on rates of change in permafrost.

As controlled experiments in climate-change, long-term provenance tests are helping to unravel plant-climate relationships. Analyses show that for *P. sylvestris* and *Larix* spp. of Siberia and for *P. engelmannii* of USA, accommodating unmitigated global warming will require a wholesale redistribution of genotypes across the landscape to maintain growth and productivity. Yet, effects of a warming climate should be much more positive for the Siberian species than for *P. engelmannii*, even though the climate is expected to warm 6-8 ºC in Siberia but only 2-3 ºC in western USA. This difference in response results because the distribution of genotypes is controlled not by climate alone, but by an interaction between adaptation to climate and competition. While genotypes occur where they can be competitively exclusive, most nonetheless have been competitively excluded from their climatic optima. Most populations, therefore, exist in climates that are colder than the optimal for their growth, productivity, and survival, with the discrepancy between the inhabited and the optimal climate increasing with the severity of the climate.

In south-central Siberia, *P. sylvestris* and *Larix* spp. inhabit climates that are among the coldest within their respective distributions. Populations tend to exist far from their climatic optima, and effects of a warming climate should be highly positive as cold tolerant populations are replaced by those of higher growth potential. Some climatypes should disappear; others should arise; but the areal extent of all should change. *P. sylvestris* genotypes projected to be the best suited for the climate of 2100 in the mountains of southern Krasnoyarsk Territory exist today in the Altai Republic and southern Ural Mountains, regions which today are 700-1200 km distant. By contrast, in USA, *P. engelmannii* inhabits the mildest climates within its distribution; populations therefore should exist near or at their climatic optima. Consequently, effects of a warming climate should be highly negative with extirpation commonplace as the contemporary climatypes are pushed upwards and northwards.

Conclusions: (1) when converted to variables of known physiological impact (e. g., degree-days), a change of a few degrees in mean annual temperature is projected to have dramatic effects on the vegetation at all levels of organization, from the biome to the species and population; (2) accommodating global warming will require a redistribution of genotypes within species to maintain adaptedness; (3) the culprit is not so much the amount of change as the speed; (4) maintaining forest growth and productivity in the face of global warming will require the participation of mankind in the evolutionary process; and (5) buy today for your grandkids or great grandkids estates in the soon-to-be equitable Siberian or Yukonian climates.