REVISITING CLIMATE CHANGES
ISOTOPE STUDIES OPEN SCIENTIFIC WINDOWS TO THE PAST

JOHN GIBSON AND PRADEEP AGGARWAL

Earlier this year, scientists warned that "an increasing body of observations gives a collective picture of a warming world and other changes in the climate system". The conclusion came from the third assessment report of the Intergovernmental Panel on Climate Change (IPCC).

Today, it is widely accepted that recent warming is largely a product of enhanced greenhouse gas concentrations in the atmosphere derived from post-industrial combustion of fossil fuels and biomass energy sources. However, great uncertainty remains regarding the causal relationships between specific parameters and climate phenomena, and regarding the impacts of climate change on the earth's water cycle.

Water is a basic need for human existence and even under the present climatic conditions, freshwater is a very limited resource on the earth. Less than 0.01% of all water is freshwater that is accessible for human consumption. The impacts of climate change on the earth's freshwater resources will have wide-ranging implications for sustainable human development.

Although widespread environmental problems -- such as melting sea and glacier ice, higher surface air temperatures, intensification of weather patterns, ecosystem disruption, and rising sea levels -- are expected to impact freshwater resources in a warmer climate, the magnitude of these changes is more difficult to predict.

The IPCC report concludes that precipitation patterns on the earth have been altered due to global warming in recent years. Precipitation has likely increased by 0.5% to 1% per decade in the 20th century over most middle and high latitudes of the Northern Hemisphere continents, and by 0.2% to 0.3% per decade over tropical (10°N to 10°S) land areas. On the other hand, parts of Asia and Africa have experienced increased intensity of droughts in recent decades, revealing a more complex and variable pattern of regional changes.

To understand complex changes, we must first appreciate that the earth's climate and hydrological cycles are fundamentally linked. The atmospheric heat engine is driven primarily by the energy exchange associated with the condensation of water. Water vapor is also one of the most abundant and important greenhouse gases in the atmosphere, together with other trace gases such as carbon dioxide that are influenced more directly by human activities.

We must also appreciate that mitigation or reversal of complex changes may be difficult. This is due to the interdependency of climate change processes that have operated for long periods of time prior to human industrial activity. Climate change is not a new phenomenon, although the current scope of change seems unprecedented. Severe changes in the earth's climate have occurred in the past, and are likely to occur in the future.

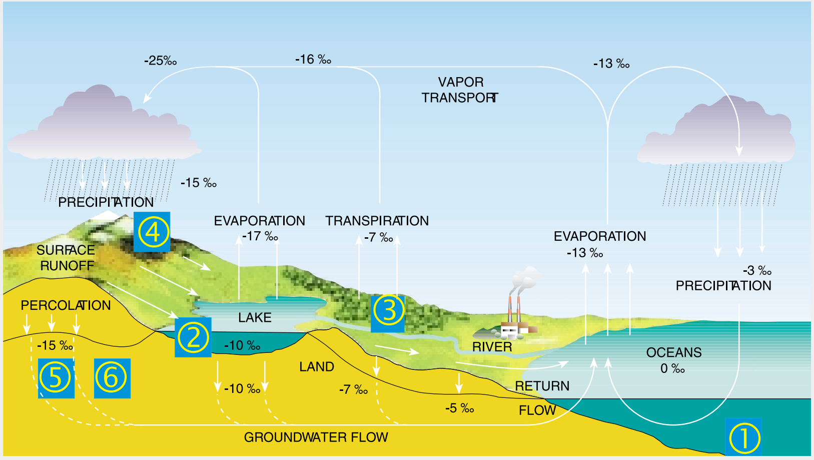
One of the high priority areas for action identified in the IPCC report is the need for improved reconstructions of past climate periods. Understanding the causes of past climate changes is, therefore, an important part of climate change research, and is the only direct way to separate industrial versus pre-industrial climate controls. In this way, the past becomes the key to the present in the study of climate change.

Studying past climate changes has been complicated by the long-time periods and large spatial scales involved. To some extent, climate change has been studied using instrumental records, such as measurements of temperature, humidity, greenhouse gases, water levels, and glacier and sea-ice. Such records are important, but they permit only a limited view. They rarely span more than a century of environmental

Mr. Gibson is a staff member in the IAEA's Isotope Hydrology Section and Mr. Aggarwal is Section Head.

EARTH'S WATER CYCLE

The drawing shows the hydrological cycle and the distribution of isotopes under present conditions. Numbers denote nodes in the water cycle where isotope archives that can be dated are preserved for use in reconstructing past isotope compositions and associated climatic changes. There are many such archives. including: (1) ocean sediments, (2) lake sediments, (3) wood cellulose from tree rings, (4) snow and glacier ice, (5) deep groundwater, and (6) cave deposits.



change information in selected locations where monitoring has been diligently conducted. As the earth system is inherently dynamic and old, it is difficult to unravel the fluctuations from long-term trends, and especially to identify the consequences of human activities.

Isotopes are one important tool used to extend spatial and temporal analysis of the relevant climatic processes. Both radiogenic and stable isotopes have been an important resource for the study of climate-related parameters. These parameters include surface air temperature, relative humidity of the atmosphere, and amount of precipitation.

In addition, the dynamics, transport and mixing processes in the atmosphere governing climatic conditions and air-sea interactions can be investigated through measurements of radioisotopes. The isotopes are like natural data-loggers or fingerprints occurring within the water molecule and within chemical substances and trace metals that are dissolved in water.

Among the most important tracers are isotopes of oxygen and hydrogen contained within the water molecule. Variations in the ratios of these isotopic species in water can be used to extract information on the history of a water parcel, such as whether it is has been evaporated, mixed, or condensed. Present day isotope patterns are found to be correlated with present day hydrological processes. The primary source of data for this analysis has been the Global Network for Isotopes in Precipitation (GNIP), a joint programme of the IAEA and World Meteorological Organization (WMO).

At specific nodes within the water cycle, isotopic signatures and their changes in time are preserved in various depositional archives. *(See illustration.)* Variations in isotope compositions of these archives provide a window to past hydrological and climate systems. Isotopes in ocean and lake sediments, tree rings, glaciers and ice caps, cave deposits, and groundwater, all provide information on how hydrological and climate systems change over time.

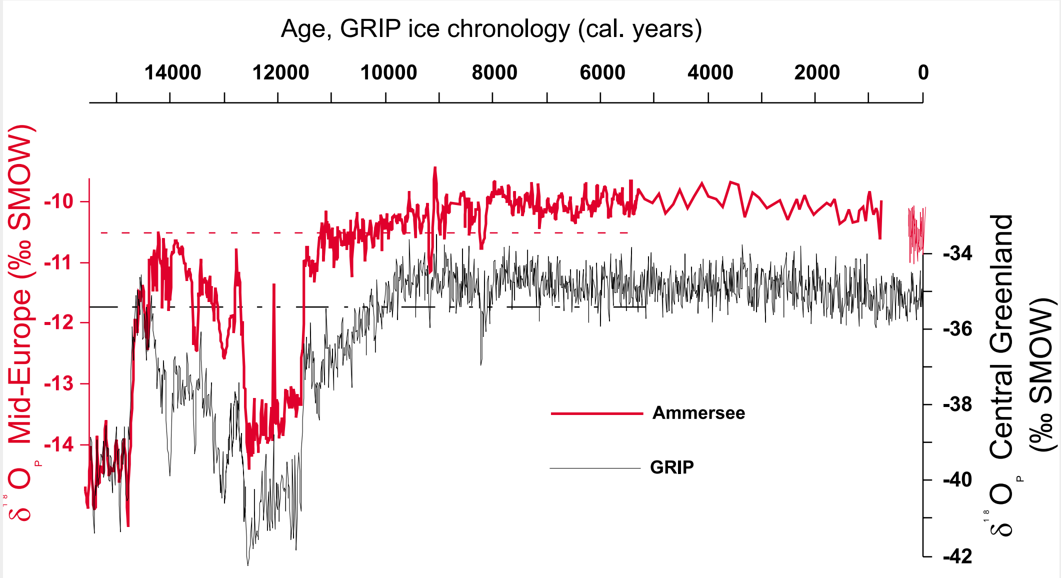
The most recent climate change in the earth's history is that related to the last glacial maximum (LGM) that occurred about 21,000 years before present. While earth surface temperature declined globally during the LGM, the climate during and after the LGM was quite variable with intermittent warming and cooling periods. The variability in climate appears to have occurred very rapidly, on a scale of few decades to a few years.

The origin and causes of this climate change and variability, however, are yet to be fully understood. Isotope records in ice cores and ocean and lake sediments have been one of the most important proxy records for understanding the climate change and variability at the LGM.

Evidence that the earth's hydrological cycle is deeply intertwined with the climate system can be seen in the isotope records from ice cores and lake sediments. Isotopic signals in an ice core from Greenland and lake sediments in Germany suggest that the water cycle has had a long history of fluctuations over the past 16,000 years. *(See graph, page 4.)*

Such fluctuations tell us about the interdependency of earth

ISOTOPE CHANGES IN ICE CORES AND LAKE ARCHIVES



The graph shows examples of isotopic changes in a Greenland ice core (GRIP) and a lake archive (Ammersee, Germany) over the past 16,000 years interpreted mainly as temperature signals. Higher delta values of oxygen-18 reflect warmer climatic conditions.

Source: based on U. v. Grafenstein, H. Erlenkeuser, A. Brauer, J. Jouzel, S. Johnsen (1999): A mid-European decadal isotope-climate record from 15,500 to 5,000 years B.P. - Science 284, 1654-1657.

processes and improve our understanding of climate change. Specifically, the records reveal more variable and colder climatic conditions (more negative delta values) than the present at about 11,000 years ago, with remarkably consistent overall trends in both Greenland and Germany. More stable, warmer conditions are inferred after 8000 years ago, once the Scandinavian and Laurentide ice sheets would have almost fully receded.

The science of climate change is dynamic. The IAEA contributes to studies via coordination of climate research, participation and support for international scientific programmes, and dissemination of isotope technology and applications. The third quadrennial scientific gathering on the use of isotopes for studying environmental change was held at the IAEA in Vienna 23-27 April 2001. The Conference -- attended by 150 experts from 38 countries and seven international organizations -- served as an important forum for presentation of results, discussion of ideas and concepts, establishment of international collaboration, and identification of avenues for future research.

Selected highlights of issues discussed include:

- Isotopes are being used as validation tools for predicting impacts of deforestation of the Amazon Basin and for examining the past isotope signals of El Niño events.
- Isotope signatures in ice cores from low-latitude environments are showing similar temperature signals to polar ice cores, suggesting widespread (global) changes in the past.
- Isotopes are being used in the World Ocean Circulation Experiment to trace the movement, mixing and residence time of oceanic circulation patterns. Changes in ocean circulation are one of the most important factors controlling the variability of the present climate.
- Isotopes are being used to study the past climate from groundwater aquifers in Europe, Asia, Australia, Africa, and the Americas.

Isotope-based research plays an important role in understanding past climate change. It is this understanding of past changes that holds the key to predicting future changes. These changes may not only influence global temperatures, but also energy needs, availability of drinking water, and adequate food supplies. In this sense, isotopes are invaluable tools that help scientists look "back to the future" to develop options for minimizing adverse effects of the world's dynamic and changing climate. ❐