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Research Statement

By training, I am a geophysicist specializing in geothermics. My major research interests are (1) climate reconstruction based on borehole temperatures, (2) subsurface thermal environmental change as part of global climate change, (3) retrieving signals of Earth's energy budget from lunar temperature data, (4) geoinformatics and numerical modeling, and (5) planetary heat flow and thermal structure.

1. Climate Reconstruction Based on Borehole Temperatures

Due to the short history of the instrumental record, our understanding of climate history prior to industrialization must rely principally on climate proxies. But no single proxy carries the full geographic or temporal representation of climate variability. The long-term trend information preserved in borehole temperatures is complementary to the short-term variability recorded in conventional proxies. I constructed and remain the custodian of the global database of borehole temperatures for climate reconstruction. From a global perspective, climate reconstruction based on the existing data in this database indicates a temperature increase over the past five centuries of about 1 K, half of which has occurred in the 20th century alone. The magnitude of ground surface warming over the past five centuries is greater in the Northern Hemisphere than in the Southern Hemisphere. The five-century cumulative change is 1.1 K in the Northern Hemisphere and 0.8 K in the Southern Hemisphere.

I further merged the complementary information preserved in hundreds of borehole temperature profiles, the 20th century meteorological record, and an annually resolved multi-proxy model for a more complete picture of the Northern Hemisphere temperature change over the past five centuries. The integrated reconstruction suggests that the 20th century warming is a continuation of a long-term warming which began before widespread industrialization. However, the warming has been substantially accelerated since industrialization. The integration of the three bodies of information greatly improves the relationship between the reconstructed temperatures and the radiative forcing history, and offers an estimate of the transient climate-forcing response rate of 0.4 - 0.7 K per Wm^{-2} of forcing.

The broad objective of my ongoing effort at the forefront of borehole-based climate research is four-fold: 1) to further extend the spatial and temporal coverage of the global database of borehole temperatures; 2) to further refine and assess the uncertainty of borehole temperature based regional climate reconstruction; 3) to promote subsurface temperature analysis as an independent validation of proxy reconstructions and global climate model simulations; and 4) to develop/refine strategies for combining the direct but low resolution record preserved in the geothermal data with the indirect but often higher resolution record contained in traditional paleoclimatic proxies.

2. Subsurface Thermal Environmental Change as Part of Global Climate Change

As global climate changes, atmospheric warming and oceanic warming make frequent headlines. But less well known is that the land is warming too. Based on world-wide meteorological and borehole temperature records, my recent study shows that the 20th century global warming deposited about 10^{22} Joules of thermal energy into the continental landmasses. I show that if the observed global warming trend over the past 35 years were to continue over the rest of the 21st century, the continents would gain additional thermal energy more than five-fold the amount they acquired over the 20th century. Even if the global surface temperature would stabilize at the current state throughout the rest of the 21st century, the continental landmasses will continue to acquire heat from the atmosphere. At this stage of global climate change, stopping atmosphere warming is not sufficient to stop the lithosphere warming. An overall 0.7 K cooling at the global ground surface over the 21st century is required to avoid further heating of the continents.

The extraordinary 20th century warming is evidence of anthropogenic forcing in the recent global climate change. Human activities including industrialization and urbanization not only increase greenhouse gases and aerosols in the atmosphere which affect the radiation balance of the climate system, but also change the thermal environment at the surface and subsurface. Over the past decade, tremendous efforts have been devoted to improve our understanding of the anthropogenic effects on the atmospheric temperature change. In comparison, little has been done in understanding the human impacts on the subsurface temperature and their environmental consequences.

As part of the industrialization and modernization process, the population of the world is increasingly concentrated in urbanized areas. According to reports of the United Nations, the number of people living in cities is growing twice as fast as the total population growth. Both population and urbanization growth are particularly rapid in less developed regions. Urbanization alters the thermal properties of the land, changes the energy budget at the ground surface, changes the surrounding atmospheric circulation characteristics, and introduces a great amount of anthropogenic waste heat into the urban climate system. The anthropogenic thermal perturbation to the nature environmental system generally originates on the ground surface and propagates both upward to the atmosphere and downward to the subsurface.

The dominating heat transport mechanism in the subsurface is heat conduction, which is much less efficient than the heat convection of the air above the ground surface. Under many circumstances, the anthropogenic impact on subsurface temperatures could be more persistent and profound than the impact on the atmosphere. With the world wide urbanization growing at an unprecedented pace, there is an urgent need to improve our understanding of the subsurface urban heat island and its environmental, social, and economical impacts. One of my research interests is to further investigate the possible impacts of the lithosphere warming on global, continental, and regional scales, including the subsurface urban heat island effect.

3. Retrieving Signals of Earth’s Energy Budget from Lunar Temperature Data

My research interest in global climate change is expanding from Earth to the Moon. Climate change of Earth is driven by the change in its energy budget. The energy budget of the climate system of Earth represents the balance between incoming energy from the Sun in the form of solar radiation, and outgoing energy from Earth in the forms of reflected and long-wave infrared radiation. Space-borne monitoring of this radiation budget began in late 1978 by the

Nimbus 7 Earth Radiation Budget Experiment. However, the first important observation from deep space of both incoming and outgoing radiation might have been made inadvertently by the Apollo 15 and 17 missions to the Moon three decades ago.

There is no complication of an atmosphere and hydrosphere in the climate system of the Moon. Temperature at the lunar surface is determined directly by the radiation it receives from the Sun and Earth. Moreover, lunar surface temperature is far more sensitive to radiation during its nighttime when radiation is weak than during its daytime when radiation is intense. Lunar regolith is an amplifier of the thermal signal of the terrestrial radiation budget. Although solar radiation is four orders greater than terrestrial radiation on the Moon, the thermal signature of possible terrestrial radiation variation could be even more significant than that of possible variations in solar radiation.

Due to the shallow deployment of the Apollo Lunar Heat Flow Experiment, six thermometers at the Apollo 15 site and two at the Apollo 17 site designed for measuring subsurface temperature ended up measuring surface temperature instead. My preliminary analysis of the 3.5-year Apollo 15 temperature time series reveals different characteristics in the lunar daytime and nighttime surface temperatures.

Using the JPL Horizons Ephemeris System, the observed daytime surface temperature change over the entire observation period can be reasonably well explained by the insolation variation associated with the variations in the distance and elevation of the Sun with respect to the Apollo 15 landing site. However, while the ephemeris of the Moon predicts a nighttime cooling trend, a significant nighttime warming trend is recorded in the Apollo 15 lunar surface temperature time series. The different characteristics of the daytime and nighttime temperatures at the Apollo 15 landing site is a confirmation of both a stable radiation incoming from the Sun and a changing radiation outgoing from Earth. The observed lunar nighttime warming is consistent with the global dimming in the 1970s recorded in widespread ground-based radiation records.

Additionally, because of the absence of life and atmosphere, all the conventional proxies (such as tree-rings, pollen, corals, ice core isotopic ratio record of atmosphere) do not exist on the Moon. Subsurface temperature is the only known index that can be used for reconstructing a lunar surface temperature history. Most of the lunar surface is covered with a thick layer (meters to several tens of meters) of regolith or lunar soil. The thermal conductivity and thermal diffusivity of lunar regolith are two orders smaller than that of terrestrial crustal rocks, and hence, the signal of climate change propagates extremely slowly in the near-surface environment on the Moon. My numerical experiment shows that the climate signal of the past 300-year surface temperature history is confined within the depth of about 20 meters of the regolith.

4. Geoinformatics and Numerical Modeling

Another area of great interest to me is geoinformatics and numerical modeling of geological processes. In addition to a B.Eng., a M.Sc., and a Ph.D. in geology, I also hold a M.S.E in computer science in engineering. In the course of my heat flow and climate research, numerical modeling has been an important vehicle. I used the finite element method in heat flow topographic correction, hydrothermal effect simulation, and basin thermal history modeling. The functional space inversion technique is the major tool of my recent efforts in reconstructing a climate history from borehole data.

My interest in information technology is mainly in the application of database and artificial intelligence techniques. I have extensive experiences in data warehousing, data mining, database system management and administration, database programming, Microsoft SQL Server, Microsoft Access, Oracle, Statistical Analysis System (SAS), and Geographical Information Systems (GIS). While continuing my earth science research, I worked for a software company from January 2000 to March 2006 as a senior software engineer. My major responsibilities in the company include the Database Setup Wizard that creates and upgrades the underlying database schema of their financial MPC (management, planning, and consolidation) application suite; Data Loader module that is embedded with business intelligence to load financial data into the MPC database and maintain the data integrity for the application; User Security module that allows the administrator to assign different levels of database privileges to different users; Automatic Build program that enables scheduled building of the MPC installation setup for routine testing and for commercial release. My software engineering skills include Visual C++, Visual Basic, Fortran, InstallShell, Visual Build, AWK, Unix shell scripting.

5. Planetary Heat Flow and Thermal Structure

Before I left the Institute of Geology of the Chinese Academy of Sciences in Beijing to join the Geothermal Lab of the University of Michigan in 1992, I was among the most active scientists in the area of heat flow study in China. I am the compiler of the first and second editions of the heat flow data in the continental area of China. I analyzed the relationships among heat flow and radioactive heat production, heat flow and *Pn* velocity, heat flow and the Curie depth derived from aeromagnetic survey, and heat flow and the depth of the Moho surface deduced from deep seismic sounding. I analyze the regional deep thermal structure of the lithosphere based on the above relationships. Results show that Southwest China including the Tibetan Plateau is characterized by a warm crust and cool mantle due to an unusually high crustal/mantle heat flow ratio. By contrast, the lithosphere of East China is characterized by a relatively cool crust overlying a warm mantle, a consequence of ongoing mantle uplift and crustal extension. I was a key contributor to the *Atlas of Geophysics in China* (Publication 201 of the International Lithosphere Program), responsible for the chapters Terrestrial Heat Flow, Temperature at the Moho, and Thickness of the Thermo-Lithosphere of this atlas.

Planetary heat flow carries information on the evolution history, thermal structure, and bulk chemical composition of a planet. So far Earth and the Moon are the only two planetary bodies where in situ heat flow measurements have been attempted. On Earth, tens of thousands of terrestrial heat flow measurements have been made on the land and at ocean bottom. In contrast there are only four measurements from the Moon, two from the Apollo 15 landing site located in the Procellarum KREEP Terrane and the other two from the Apollo 17 site in the Feldspathic Highlands Terrane. The global representativeness of the Apollo heat flow measurements remains controversial. Recently I have been involved in an effort to develop a long-lived geophysical network on the Moon. My recommendation for new lunar heat flow experiment is reflected in "The Scientific Context for Exploration of the Moon: Interim Report" recently published by the National Research Council (2006).

I am a member of the International Heat Flow Committee of the International Association of Seismology and Physics of the Earth's Interior, a 20-seat panel guiding and coordinating worldwide geothermal research activities.