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Paleoclimate from Mount Everest Ice Cores

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Paleoclimate from Mount Everest Ice Cores

Project Participants

Senior Personnel

Name: Mayewski, Paul
Worked for more than 160 Hours: Yes
Contribution to Project:
overseeing the project

Name: Hamilton, Gordon
Worked for more than 160 Hours: Yes
Contribution to Project:
Analysing GPS survey data.

Name: Kreutz, Karl
Worked for more than 160 Hours: Yes
Contribution to Project:
Analysis of stable isotopic composition (Delta D and O18) for ice core samples.

Name: Kang, Shichang
Worked for more than 160 Hours: Yes
Contribution to Project:
Field expedition, preparing ice core samples and interpreting ice core data.

Name: Kurbatov, Andrei
Worked for more than 160 Hours: Yes
Contribution to Project:
Observing vocanic signals from ice core records.

Post-doc

Graduate Student

Name: Kaspari, Susan
Worked for more than 160 Hours: Yes
Contribution to Project:
PhD student involved in field, laboratory, and interpretation activities for this project. Supported by this project and University of Maine.

Name: Grigholm, Bjorn
Worked for more than 160 Hours: Yes
Contribution to Project:
Laboratory analyses

Undergraduate Student

Technician, Programmer

Name: Introne, Douglas

Worked for more than 160 Hours: Yes
Contribution to Project:
Stable isotope analyses

Name: Sneed, Sharon
Worked for more than 160 Hours: Yes
Contribution to Project:
Ion chromatograph analyses

Name: Handley, Michael
Worked for more than 160 Hours: Yes
Contribution to Project:
Trace element analyses

Other Participant

Research Experience for Undergraduates

Organizational Partners

Chinese Academy of Scineces (Public)
(1)Partial financial support for field work
(2)Ice core drilling support

CNRS (France)
CNRS staff provided del18 of O2 and CH4 measurements for Everest ice to assess age of the core.

Tibetan Plateau Institute

Chinese Meteorological Administration

Other Collaborators or Contacts

Our Everest and previous Asian ice core activities are now part of a larger emerging project dedicated to developing an array of ice core reconstructions of past climate over Asia. Collaborators, in addition to University of Maine, P. Mayewski) include:

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Activities and Findings

Research and Education Activities:

Core Collection/ Analysis:

Everest 2002- East Rongbuk Col:
N 27 59, E 86 55, 6518 m
A 108m ice core was drilled to bedrock in Spring 2002 at East Rongbuk Col. The ice core was transferred to the University of Maine and melted using a continuous melter system. The upper 87 m were melted at ~4 cm resolution, and the bottom 20 m were melted at ~2 cm resolution. The samples were analyzed for soluble ions (Na+, K+, Mg2+, Ca2+, Cl-, NO3-, SO42-) using ion chromatography, and for dD. The data shows a clear annual signal, and the dating of the core is calibrated to known nuclear bomb horizons from measurements of 137Cs and 90Sr resulting in a 1500 year long record. Selected sections of the core were analyzed for d18O to determine deuterium excess (d).

Mt. Nyainqentanglha:
N 30 24, E 90 34, 5860m
The Nyainqentanglha Mountains are located north of the Himalayas and south of the Tanggula mountains. No previous ice core research has been done in this region, thus an ice core from the Nyainqentanglha Mountains will improve spatial and temporal understanding of climate across the Tibetan Plateau and in Asia. In 1999 a 30 m ice core was recovered from the pass between Nalong and XiBu Glaciers (5860 m) at the base of Mt. Nyainqentanglha as part of a reconnaissance expedition. The ice core was analyzed for dD and 137Cs, and an annual signal is preserved in the record In October 2003 a joint Chinese-US program (CAREERI and Climate Change Institute, University of Maine) returned to Mt. Nyainqentanglha. Two ice cores were recovered from this site. This work is in addition to that stated in our original proposal, but is included in our work plan to investigate spatial gradients in climate. A 106 m ice core was recovered from the pass, and a 124 m ice core to bedrock was recovered 200 m northwest of the pass. A solar powered automatic weather station (AWS) was installed at the pass. Water samples were collected from an adjacent river and Nam Co Lake. The 124 m ice core is stored at the University of Maine ice core facility. The ice core is being analyzed for soluble ions (Na+, K+, Mg2+, Ca2+, Cl-, NO3-, SO42-), stable isotopes (dD), and black carbon.

Mt. Geladandong:
33 12Æ 46ö N, 91 09Æ15öE 5800 m
In the spring of 2004 an 87 m ice core was recovered from the South Geladandong Flat topped Glacier in the central Tibetan Plateau in a collaboration between the Climate Change Institute and CAREERI. Accumulation is ~36 cm w.e. This work is in addition to that stated in our original proposal, but is included in our work plan to investigate spatial gradients in climate. The ice core was sampled at 2.5 cm resolution for soluble ions (Na+, K+, Mg2+, Ca2+, Cl-, NO3-, SO42-) and stable isotopes (dD) in August-September 2004. The ice core was sampled at 70 cm resolution for alpha particles using a heavy metal resin column, and at ~1 m resolution for total b-activity to calibrate the ice core to known bomb horizons. The ice core was also sampled at 70 cm resolution for black carbon analysis.

Much of the foregoing is part of a PhD thesis for Susan Kaspari and all will be done in collaboration with our Chinese colleagues.

Findings: (See PDF version submitted by PI at the end of the report)

The primary focus of this research is the production and interpretation of instrumentally calibrated proxies for climate (notably atmospheric circulation) and records of change in the chemistry of the atmosphere over Asia. Examples of the 22 published, in press, or in review results from our research include:

S. Kang, P. A. Mayewski, D. Qin, Y. Yan, S. Hou, D. Zhang, J. Ren, K. Kruetz, 2002. Glaciochemical records from a Mt. Everest ice core: relationship to atmospheric circulation over Asia. Atmospheric Environment, 36(21): 3351-3361.
This paper demonstrates that:
1. The Everest ice core record comprises two assemblages (determined using empirical orthogonal factor statistics (EOF)) of crustal species, each transported from different source regions during different seasons.
2. EOF1-ions represent the majority of the crustal species and are related to winter atmospheric circulation patterns. These species are mainly transported from the arid regions of central Asia during the winter dry season.
3. EOF2-ions represent crustal species transported by summer atmospheric circulation from local/regional sources in the northern and southern Himalayas.

S. Kang, P. A. Mayewski, D. Qin, Y. Yan, S. Hou, D. Zhang, 2002. Twentieth century increase of atmospheric ammonia recorded in Mt. Everest ice core. Journal of Geophysical Research, 107(D21): 4595, 10.1029/2001JD001413, ACL13-1-ACL13-9.
This paper demonstrates that:
1. Higher NH4+ concentrations are associated with an enhanced winter Mongolian High and a deepened summer Mongolian Low.
2. A positive relationship also exists between NH4+ concentrations and regional temperature changes in GIS Box 36 indicating that an increase in temperature may contribute to the strengthening of natural ammonia emissions (e.g. from plants and soils).
3. A close positive correlation between NH4+ and acidic species (SO42- plus NO3-) concentrations suggests that a portion of the increase in NH4+ concentrations is contributed by enhanced atmospheric acidification.
4. Anthropogenic ammonia emissions from enhanced agricultural activities and energy consumption over Asia in concert with population increase since the 1950s are a significant factor in the dramatic increase of NH4+ concentrations during the last few decades.

Update as of project termination Oct. 2005:
Abstract from a paper to be submitted:
Blocking of the South Asian Monsoon by the Asian High Since ~1400 A.D. from a Mt. Everest Ice Core
by Kaspari, S., P. Mayewski, S. Kang, S. Sneed, K. Kreutz, D. Introne, R. Hooke, K. Maasch1 D. Qin, S. Hou, and J. Ren

Analysis of a 108m high-resolution ice core drilled to bedrock from Mt. Everest covering the last 1500 years indicates a weakening of the Asian monsoon since ~1400 A.D. Empirical orthogonal function (EOF) analysis on the major ion (Na+, K+, Mg2+, Ca2+, Cl-, NO3-, SO42-) and dD time-series demonstrates that the Everest site is influenced by continental air masses associated with the Asian high pressure system and marine air masses associated with the South Asian monsoon. Everest Ca2+ (Cl-) is positively (negatively) correlated with NCEP/NCAR reanalysis surface pressure from May-September over central Asia from 1948-2001, indicating that when pressure is relatively higher (lower) over central Asia more continental (marine) air masses penetrate the Everest site. An inverse correlation of Everest dD and June-September NCEP/NCAR reanalysis precipitation rate from 1948-2001 confirms the results of our previous studies that the amount effect is the primary control on dD in the Everest region (Kang et al., 2002), however temperature and changes in moisture source also may affect dD. Increased continental and decreased marine air masses since ~AD1400 suggests higher pressure over central Asia, and a weakening of the monsoon in the Everest region as a consequence of blocking. Increasing dD and decreasing net mass balance provide further support for a weakening of the South Asian monsoon over the Everest region. Proxy records from low elevation sites south of the Himalayas indicate a strengthening over the same time period. These regional differences are consistent with higher pressure over Asia during summer (more blocking) and a southward shift in the mean summer position of the Intertropical Convergence Zone, as supported by a reduction in seasonal differences of insolation.

Research to be conducted over the next 12 months related to this project:
All major ion (Na+, K+, Mg2+, Ca2+, Cl-, NO3-, SO42-) and stable isotope analyses proposed for this project have been completed. Results appear in a series of published papers (see this report) and near submission (see abstract above). Through this NSF project we have been able to develop the highest resolution, best dated paleoclimate record thus far available from Asia. We will now embark on the analysis of a companion set of co-registered trace element analyses (using sample volumes maintained for this purpose during core processing)not originally specified in the project. Trace metals (eg., Rb, Ba, Nd, and Pb) are present in ice cores at ppt levels, and the sensitivity of an ICP-MS is necessary. The CCI UM NSF-MRI supported Finnigan Element 2 ICP-MS with an ESI Apex high sensitivity sample introduction system will be used for the analysis of, for example, cadmium, lead, barium, vanadium, iron, manganese, zinc, chromium, cobalt, aluminum, calcium, sulfur, titanium, copper, uranium, cesium, and the rare earth elements (Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, La). For the rare earth elements the detection limit is around 1ppq and for the other elements around 1ppt.

Training and Development:

1. Work study and hourly undergraduate students trained to process and sample ice cores in the freezer.
2.Graduate students familiarized with all laboratory measurements.
3.Graduate students taught to statistically analyse ice core data using Matlab.
4.Graduate students involved in field research.

Outreach Activities:

Presentations dealing with the Mt. Everest expedition given to University of Maine undergraduate students and local primary school students.

Numerous tours of our facilities given to students from our region.

Expedition information appears on our website (www.climatechange.umaine.edu).

Journal Publications

Shichang Kang, Paul A. Mayewski, Dahe Qin, Yuping Yan, Dongqi Zhang, Shugui Hou, Jiawen Ren, "Twentieth century increase of atmospheric ammonia recorded in Mount Everest ice core", Journal of Geophysical Research, p. 4595, vol. 107, (2002). Published

S. Kang, P. A. Mayewski, D. Qin, Y. Yan, S. Hou, D. Zhang, J. Ren, K. Kreutz, "Glaciochemical records from a Mt. Everest ice core: relationship to atmospheric circulation over Asia", Atmospheric Environment, p. 3351, vol. 36, (2002). Published

Shichang Kang, Karl J. Kreutz, Paul A. Mayewski, Dahe Qin, Tandong Yao, "Stable-isotopic composition of precipitation over the northern slope of the central himalaya", Journal of Glaciology, p. 519, vol. 48, (2002). Published

S. Kang, P. A. Mayewski, Y. Yan, D. Qin, J. Ren, T. Yao, "Dust records from three ice cores: relationships to spring atmospheric circulation over the Northern Hemisphere", Atmospheric Environment, p. 4823, vol. 37, (2003). Accepted

Shichang Kang, Paul A. Mayewski, Dahe Qin, Sharon A. Sneed, Jiawen Ren, Dongqi Zhang, "Seasonal differences in snow chemistry from the vicinity of Mt. Everest, central Himalayas.", Atmospheric Environment, p. , vol. 38, (2004). Accepted

Hou Shugui, Qin Dahe, Zhang Dongqi, Kang Shichang, Paul A. Mayewski, C. P. Wake, "A 154a high-resolution ammonium record from the Rongbuk Glacier, north slope of Mt. Qomolangma (Everest), Tibet-Himal region.", Atmospheric Environment, p. 721, vol. 37, (2003). Published

Zhang Dongqi, Qin Dahe, Hou Shugui, Ren Jiawen, Paul A. Mayewski, Kang Shichang, "Climatological significance of d18O from the 80.36 m East Rongbuk ice core, Mt. Everest.", Science in China (D), p. 264, vol. 33, (2003). Published

Cameron P. Wake, Paul A. Mayewski, Shichang Kang, "Climatic interpretation of the gradient in glaciochemical signals across the crest of the Himalaya.", In: L. D. Cecil, E. Steig, and L. Thompson (eds), Earth Paleoenvironments: Records Preserved in Mid and Low Latitude Glaciers., p. , vol. , (2004). Accepted

Kreutz K.J., Kang S., Mayewski P.A., Introne D.S., Qin D., Wake C., Aizen V.B., Cecil L.D., "Spatial deuterium excess patterns in high-elevation Asian precipitation", Geochimica et Cosmochimica Acta, p. 418, vol. 66, (2002). Published

Qin Dahe, Hou Shugui, Zhang Dongqi, Ren Jiawen, Kang Shichang, P.A. Mayewski and C.P. Wake, "Preliminary results from the chemical records of an 80.4 m ice core recovered from the East Rongbuk Glacier, Mt. Qomolangma (Everest).", Annals of Glaciology, p. 278, vol. 35, (2002). Published

Hou Shugui, Qin Dahe, Zhang Dongqi, Ren Jiawen, Kang Shichang, P. A. Mayewski, C. P. Wake, "Comparison of two ice core chemical records recovered from the Mt. Qomolangma (Everest) region.", Annals of Glaciology, p. 266, vol. 35, (2002). Published

Zhang Dongqi, Qin Dahe, Hou Shugui, Ren Jiawen, Kang Shichang.
, "Glaciochemistry from fresh snow and snow pits in the Mt. Everest Regions (In Chinese with English Abstract).", Journal of Lanzhou University (Natural Sciences), p. 119, vol. 38, (2002). Published

Kang, S., Qin, D., Mayewski, P.A., Sneed, S.B. and Yao, T., "Chemical composition of fresh snow on Xixipangma peak, central Himalayas during the summer monsoon season.", Journal of Glaciology, p. 337, vol. 48, (2002). Published

Kang, S. Qin, D., Mayewski, P. and Wake, C, "Recent 180 years of oxalate (C204-2) recovered from a Mt. Everest ice core and environmental implications", Journal of Glaciology, p. 155, vol. 47, (2001). Published

Qin, D., Mayewski, P., Wake, C., Kang, S., Jiawen, J., Hou, S., Yao, T., Yang, Q., Jin, Z. and Mi, D., "Evidence for recent climate change from ice cores in the central Himalayas", Annals of Glaciology, p. 153, vol. 31, (2001). Published

Kang,S., Qin, D., Yao, T., and Mayewski, P.A., "Fresh snow chemistry from high mountain regions in central Himalayas.", Chinese Geography Science, p. 218, vol. 10, (2000). Published

Kang, S., Qin, D. Mayewski, P.A., Wake, C.P. and Ren, J., "Recent 200 a climatic records in the Far East Rongbuk ice core, Mt. Qomolangma (Everest), Himalayas", Journal of Glaciology and Geocryology, p. 211, vol. 22, (2000). Published

Kang,S., Qin, D., Mayewski, P.A., Wake, P.A., and Ren, J.,, "Climatic and environmental records from the Far East Rongbuk ice core, Mt. Qomolangma (Everest).", Episodes, p. 176, vol. 24, (2001). Published

Hou, S., Chappellaz, Jouzel, J., J., Chu, P., Masson-Delmotte, V., Qin, D., Kang, S., Raynaud, R., Mayewski, P.A. and Lipenkov, V.Y., "Summer temperatures for the past two millennia using air content along two Himalayan ice cores.", Climate of the Past, p. , vol. , ( ). Accepted

Kang, S., Qin, D., Mayewski, P.A., Kaspari, S., Ren, J. and Hou, S., "Recent change of annual accumulation from a Mt. Nyainqentanglha ice core, southern Tibetan Plateau: relationships to atmospheric circulation over Asia.", Journal of Gephysical Research, p. , vol. , ( ). Submitted

Ye, Q., Kang, S., Hamilton, G.H., Mayewski, P.A., Chen, F., Wang, J., and Kurbatov, A., "Glacier variations in the Mt. Geladandong, central Tibetan Plateau, between 1969-2002 Using Remote Sensing and GIS techniques.", Journal of Geophysical Research, p. , vol. , ( ). Submitted

Kaspari, S., Mayewski, P.A., Kang, S., Sneed, S., Kreutz, K., Introne, D., Hooke, R., Maasch, K., Qin, D., Ren, J., "Blocking of the South Asian Monsoon by the Asian High since ~1400 A.D. from a Mt. Everest ice core.", Science, p. , vol. , ( ).

Books or Other One-time Publications

Web/Internet Site

URL(s):

http://www.climatechange.umaine.edu/Research/paleoclimate.html

Description:

This website introduces the project in details.

Other Specific Products

Product Type:

Data or databases

Product Description:

The 1998 East Rongbuk ice core data is located on the NOAA Paleoclimatological database. The website is an follows: http://www.ngdc.noaa.gov/paleo/icecore/trop/rongbuk/rongbuk.html

Sharing Information:

The NOAA database is open for every researcher.

Contributions

Contributions within Discipline:

Primary Contributions Related to the Recovery, Analysis, and Interpretation of the Mt. Everest Ice Core:

Reconstructed atmospheric ammonia variability since the 19th century and revealed the influence of anthropogenic source emissions over Asia (notably enhanced agriculture activities and energy consumption in concert with population increase since the 1950s).

Developed a calibrated proxy for Southeast Asian atmospheric circulation. This research has added a critical dimension to our understanding of Asian climate and environmental change and its relationship to the global system.

Investigated the climatological significance of the stable-isotopic composition (dD and dO18) of precipitation over the high mountains of the Himalayas as a proxy for past climate. Demonstrated that the simple temperature - isotope association suggested by previous investigators in nearby regions is more complicated. Deconvoluted the amount and temperature effect.

Developed a 1500 year long record documenting strength of the South Asian monsoon and compared this record to existing paleoclimate records to demonstrate major change ~AD1400 and over the last few decades.

Contributions to Other Disciplines:

Developed instrumentally-calibrated proxies for atmospheric circulation over central Asia that extend the climate record well beyond the instrumental era (1500 years before present). These records are of significant value to paleoclimatologists and climatologists. The existing instrumented record of climate in Asia is sparse and barely extends back 100 years. As a consequence it is not possible to assess change in climate or chemistry of the atmosphere definitively without the longer perspective offered by the Everest ice core record.

Mt. Everest is an area of considerable international interest ab=nd at the center of monitoring studies by several countries (eg., China, Nepal, Italy). The Everest ice core record provides a framework for developing these monitoring studies.

Contributions to Human Resource Development:

Graduate student training leading to a PhD in Asian paleoclimate studies (Susan Kaspari, Univ. Maine, PhD expected 2006) and lectures to undergraduates, work study, and other students on campus, in the region, nationally, and internationally.

Contributions to Resources for Research and Education:

Laboratory access for students.
Ice core data for use in classes (eg., Climatology, Climate Analysis).

Contributions Beyond Science and Engineering:

Documentation of the impact of human activities on the chemistry of the atmosphere over Asia.

A 1500 year perspective to assess change in atmospheric circulation and chemistry of the atmosphere over Asia.

Categories for which nothing is reported:

Any Book

Major Scientific findings

Glaciochemical records recovered from an 80.4 m ice core in the East Rongbuk (ER) Glacier (elevation: 6450 m) on the northern slope of Mt. Everest are used to reconstruct past climate for the period AD 1846-1997. Empirical orthogonal function (EOF) analysis of the eight major ion (SO_4^{2-}, Mg^{2+}, Ca^{2+}, Na^+, Cl^-, NH_4^+, K^+, and NO_3^-) time-series reveals inter-species relations and common structure within the ER glaciochemical data. The first two EOF series (EOF1-ions and EOF2-ions) are compared with instrumental data of sea level pressure (SLP) to demonstrate that the EOF-ions series display strong connections to winter (January) and summer (July) SLP over the region of Mongolia. The positive relationship between EOF1-ions and the Mongolian High (MongHi) series suggests that enhanced winter MongHi strengthens the transport of dust aerosols southward from arid regions over central Asia to Mt. Everest. The close correspondence between EOF2-ions and the summer Mongolian Low (MongLow) indicates that the deeper MongLow and related stronger Indian Monsoon contribute to a decrease in summer dust aerosols. The ER ice core record comprises, therefore, two assemblages of crustal species, each transported from different source regions during different seasons. EOF1-ions represents the majority of the crustal species and is related to winter atmospheric circulation patterns. These species are mainly transported from the arid regions of central Asia during the winter dry season. EOF2-ions represents crustal species transported by summer atmospheric circulation from local/regional sources in the northern and southern Himalayas.

Variations in NH_4^+ from the 1998 ER ice core are characterized by a dramatic increase since the 1950s. The highest NH_4^+ concentrations occur in the 1980s. They are about two-fold more than those in the first half of 20^{th} century. EOF analysis indicates that NH_4^+ is loaded mainly on EOF3 (60% of NH_4^+ variance) suggesting that NH_4^+ has a unique signature. Instrumental sea level pressure (SLP) and regional temperatures are used to explore the relationship between NH_4^+ variations and both atmospheric circulation and natural source strength over Asia. Higher NH_4^+ concentrations are associated with an enhanced winter Mongolian High and a deepened summer Mongolian Low. A positive relationship also exists between NH_4^+ concentrations and regional temperature changes of the GIS Box 36 (Indian subcontinent) indicating that an increase in temperature may contribute to the strengthening of natural ammonia emissions (e.g. from plants and soils). A close positive correlation between NH_4^+ and acidic species (SO_4^{2-} plus NO_3^-) concentrations suggests that a portion of increase in NH_4^+ concentrations could be contributed by enhanced atmospheric acidification. Anthropogenic ammonia emissions from enhanced agricultural activities and energy consumption over Asia in concert with population increase since the 1950s appear also to be a significant factor in the dramatic increase of NH_4^+ concentrations during the last few decades.

Stable water isotope data (δD and $\delta^{18}O$) from three groups of samples (fresh snow and snowpit samples collected on Mts. Everest and Xixabangma during field seasons in 1997, 1998 and 2001, and precipitation samples collected at Tingri Station during summer 2000) are presented and used to survey the isotopic composition of precipitation over the northern slope of the central Himalayas. Multi-year snowpit

samples on Mt. Everest have a local meteoric water line (slope = 8) close to the global value. Deuterium excess ($d = \delta D - 8\delta^{18}O$) values at Tingri are much lower than those in fresh snow from Mt. Everest probably due to differences in moisture source and air mass trajectories, as well as local weather conditions. There is no obvious seasonal trend for d values in the Mt. Everest region. A negative relationship exists between $\delta^{18}O$ and d values in both fresh snow on Mt. Everest and precipitation at Tingri. Fresh snow samples collected from different altitudes on Mt. Xixabangme allow us to investigate the altitude effect on $\delta^{18}O$ values in snow. Of four storm events, only one has an obvious altitude effect on $\delta^{18}O$ variation and a very low gradient of –0.1‰ per 100 m elevation.