assess the primary mechanisms how cyclic marine deposits are formed in the geological record. In the Deep Ivorian Basin formation of cyclic OAE3 black shales was favoured by the paleogeographic position of the drill site in the partly sheltered early Ivory Basin south of the paleo-equator and, most important, was directly linked to orbital-driven fluctuations in atmospheric and oceanic circulation. Dramatic changes in redox sensitive trace metal accumulation as well as the occurrence of molecular fossils of green sulfur bacteria provide evidence for extreme variations in redox conditions, with euxinic conditions occasionally even extending into the lower photic zone. The temporal establishment of a continuous euxinic water column about 200 km offshore the West-African coastline supports the conclusion that redox conditions in the Coniacian-Santonian tropical ocean at least occasionally were as extreme as during the Cenomanian-Turonian OAE-2, although much smaller in extent and restricted to short but repetitive periods. It has also been demonstrated that the terrigenous fraction represented by Si/Al and K/Al at Site 959 documents fluctuating supply of aeolian dust from a source area in southern Africa, represented by illite and quartz, and continental run-off from a tropical northern African source area, represented by smectite and kaolinite. Input from the two African source areas to the DIB is interpreted to document repetitive shifts in the position of the Intertropical Convergence Zone, which led to a succession of drier and wetter climate periods over western Africa. Recent results from climate modelling support such short-term fluctuations in African moisture balance/precipitation and allow to project the view from a single sample location off W-Africa to a regional or even global perspective.

## PP42D-05 1720h

### Origin of Tropical Obliquity-Dominated Sequences and Secular Trends in Deep Ocean Chemistry

Richard D Norris[1] (858-822-1868; RNorris@ucsd.edu)

Ursula Roehl[2] (uroehl@allgeo.uni-bremen.de)

Karen L Bice[3] (508-289-3320; kbice@whoi.edu)

[1]Scripps Institution of Oceanography, 308 Vaughan Hall, La Jolla, CA 92093, United States

[2]Bremen University, Geosciences Department, Bremen D-28334, Germany

[3]Woods Hole Oceanographic Institution, Mail Stop #23, Woods Hole, MA 02543, United States

A long-standing puzzle is the presence of a strong obliquity cycle in Paleogene tropical sediment cores, since orbital theory predicts that precession should be the major signal in tropical deposits while obliquity should predominate at mid and high latitudes. Drilling in tropical and warm subtropical sequences of Paleogene and Cretaceous age shows that precession-dominated and obliquity-dominated intervals may be present in the same cores. Data are based on XRF core scanning of Paleogene sections in cores form several Atlantic sites, including recently drilled, Leg 207 sites. The seeming alternation of high and low latitude signals in tropical deposits at least partly owes its origin to variations in the extent to which the record reflects surface and bottom water processes. Because bottom waters are formed mostly at high latitudes, their flow strength, corrosiveness, and other physical properties should carry a dominant obliquity signal which can be superimposed on precession-dominated tropical sedimentary records. When the sedimentary record is not highly modified by benthic processes, the precession signal dominates tropical sedimentary records, but where there are changes in deep water flow strength (which may winnow a deposit) or corrosiveness of bottom water (which dissolves surface-derived carbonate), then the mid/high latitude orbital period predominates. Obliquity signals also dominate in Neogene and late Paleogene records in part because of the onset of polar ice growth. We might expect tropical records to show some depth dependence in the kinds of orbital signals that are recorded in sediments, with shallower, less dissolved, sequences displaying a stronger precessional cycle than deeper, more dissolved sequences. The general tendency for tropical Cretaceous and early Paleogene deep sea sediments to display precessional dominance and later Paleogene and Neogene sediments to display obliquity dominance suggests an increase in deep water corrosiveness over the Cenozoic. This increase started in the middle Eocene in agreement with global estimates of changes in the depth of the carbonate compensation depth.

## PP42D-06 1740h INVITED

### Implications From a new Continuous Astronomically Calibrated Geological Time Scale Back to ∼ 42 Myrs

Heiko Pälike[1] (+46-8-16-4719; heiko@geo.su.se); Theodore C. Moore[2] (tedmoore@umich.edu); Jan Backman[1] (backman@geo.su.se); Isabella Raffi[3] (raffi@phobos.unich.it); Josep M. Parés[2] (jmpares@umich.edu); Luca Lanci[4] (llanci@uniurb.it); Nicholas J. Shackleton[5] (njs5@cam.ac.uk); Shipboard Scientific Party ODP 199

[1]Department of Geology Geochemistry, Stockholm University, Stockholm 10691, Sweden

[2]Geological Sciences, University of Michigan 2534 C.C. Little Building, 425 E. University Ave., Ann Arbor, MI 48109-1063, United States

[3]Dipartimento di Scienze della Terra, Universitario "G. D'Annunzio" Campus Universitario via dei Vestini 31, Chieti Scalo 66013, Italy

[4]Istituto di Dinamica Ambientale, Universita' di Urbino Localita Crocicchia, Urbino 61029, Italy

[5]Godwin Laboratory, University of Cambridge,, Cambridge CB2 3RS, United Kingdom

Precise, orbitally calibrated geological time scales form a pre-requisite to further our understanding of phase relationships between orbitally driven climatic processes, and to decipher the detailed mechanisms that interact to encode orbitally forced (Milankovitch) processes in the geological record. One of the great successes of ODP Leg 199 was the recovery of a high-resolution (∼1-2 cm/ky) biogenic sediment record, together with an uninterrupted set of geomagnetic chrons, as well as a detailed sequence of calcareous and siliceous biostratigraphic datum points. In addition, lithological measurements revealed clearly recognisable cycles that can be attributed to climatic change, driven by Milankovitch style orbital variations of the Earth. By integrating lithological, geochemical, and stable isotope data sets, we have now derived a long, astronomically calibrated, time scale from the Miocene into the latest Eocene from ODP Leg 199. Using additional data from ODP Legs 177 and 171B, we have generated a detailed continuous time scale back to ∼ 42 Myrs. We can contrast the encoding of astronomical forcing terms in sedimentary records from different ocean basins, latitudes, water-depths, and water masses. Our results show that the dominantly recorded orbital parameters vary as a function of the carbonate system response, with a very strong eccentricity component in the record from the deep equatorial Pacific, and a stronger obliquity component in the equatorial Atlantic. In addition, we investigate the phase relationship between astronomical forcing terms and carbonate preservation, with a potentially different response during "green-house" and "ice-house" conditions, separating the Oligocene and Eocene.

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# PP51A MCC: 3004 Friday 0800h

## Global, Hemispheric, and Regional Climate Signals During the Last Millennium I *(joint with A, H, C, GC)*

***Presiding:*** **C M Ammann,** National Center for Atmospheric Research**; P Naveau,** University of Colorado

## PP51A-01 0800h INVITED

### Spatially and Seasonally-Specific Responses to Forcing as Detected In Paleoclimate Reconstructions of Past Centuries

Michael E. Mann[1] (434-244-9955; mann@virginia.edu); J. Brad Adams[1] (434-924-4669; jba7g@virginia.edu); Caspar M. Ammann[2] (303-497-1705; ammann@ucar.edu); Ron L. Miller[3] (rmiller@giss.nasa.gov); Scott Rutherford[4] (srutherford@gso.uri.edu); Gavin A Schmidt[3] (gschmidt@giss.nasa.gov); Drew T Shindell[3] (dshindell@giss.nasa.gov)

[1]University of Virginia, Department of Environmental Sciences, 291 McCormick Road, Charlottesville, VA 22904, United States

[2]National Center for Atmospheric Research, Climate and Global Dynamics Division, 1850 Table Mesa Drive, Boulder, CO 80307-3000, United States

[3]NASA Goddard Institute for Space Studies and Center for Climate Systems Research, Columbia University, New York, NY 10025, United States

[4]Department of Environmental Sciences, Roger Williams University, Bristol, RI 02804, United States

We will review recent progress in proxy-based reconstruction and modeling of climate changes in past centuries. Empirical, proxy-based surface temperature reconstructions will be discussed, with an emphasis on the seasonal and spatial details of patterns of past variation. Estimated patterns of change will be interpreted in the context of the modeled seasonal and regional response to estimated radiative forcing changes in past centuries. The likely importance of radiatively forced changes in both the Northern Annular Mode ('NAM')/Arctic Oscillation ('AO') and the El Nino/Southern Oscillation ('ENSO') will be addressed.

URL: http://holocene.evsc.virginia.edu/Mann/research/research.html

## PP51A-02 0815h

### Northern Hemisphere Regional Climate Change during the Last Millenium

Drew T Shindell[1] (12126785561; dshindell@giss.nasa.gov)

Gavin A Schmidt[1] (gschmidt@giss.nasa.gov)

Michael E Mann[2] (mann@virginia.edu)

Ron L Miller[3] (rmiller@giss.nasa.gov)

[1]NASA Goddard Institute for Space Studies and Center for Climate Systems Research, Columbia University, 2880 Broadway, New York, NY 10025, United States

[2]Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22902, United States

[3]NASA Goddard Institute for Space Studies and Department of Applied Physics and Applied Mathematics, Columbia University, 2880 Broadway, New York, NY 10025, United States

We examine the regional climate response to variability in volcanic aerosols and solar irradiance in a stratosphere-resolving general circulation model (GCM). The simulated surface temperature anomalies are compared with historical data and proxy-based reconstructions at various timescales, including a new analysis of the mean climate response pattern during the cold-season following large tropical volcanic eruptions back to the beginning of the 17th century. This anomaly pattern strongly resembles the Arctic Oscillation (AO) or Northern Annular Mode (NAM), and with our four-century record, the mean response is statistically significant over much of the Northern Hemisphere land area. The dynamical climate response to injections of volcanic aerosols into the stratosphere is well simulated in many GCMs, demonstrating the robustness of the AO/NAM surface response to stratospheric temperature and wind anomalies. Due to opposing dynamical and radiative effects, we show that the long-term (decadal and longer) regional response to volcanic eruptions is not significant compared to unforced variability for either the winter or the annual average, however. Solar variations induce shifts in the AO/NAM in a similar manner to the short-term volcanic response. In contrast to the one to two year timescales for large volcanic eruptions, solar variations can persist for decadal or longer timescales, creating a long-term regional response which greatly exceeds unforced variability. Solar forcing thus appears to have been the most important external driver of long-term regional climate anomalies during the last millennium.

## PP51A-03 0830h

### Centennial scale climate variations and their spatial dimensions in coupled GCM simulations of the last millennium

Caspar M Ammann[1] (1-303-497-1705; ammann@ucar.edu)

Fortunat Joos[2] (41-31-631-4461; joos@climate.unibe.ch)

Robert A Tomas[1] (1-303-497-1311; tomas@ucar.edu)

[1]Climate and Global Dynamics Division, National Center for Atmospheric Research 1850 Table Mesa Drive, Boulder, CO 80307-3000, United States

[2]Institute of Climate and Environmental Physics, University of Bern Sidlerstrasse 9, Bern, BE 3012, Switzerland

Multi-decadal and century scale climate variations have been proposed to occur either purely internal to the climate system or in response to external perturbations. The separation between these different sources is not only important for our understanding of past climates but it also bears significant implications for what we have to expect from the future. External forcing, such as solar irradiance variations and explosive volcanism, has recently been found to behave surprisingly linear both in terms of response to individual forcings as

well as in combination of each other. But it is unclear if this also holds back in time. In particular, when including the most significant natural climate variations during the last millennium, namely the episodes of the Little Ice Age, it remains to be demonstrated that no low-frequency variation from inside of the climate system could be the main driver. In fact, such an internal cause has been proposed using global ocean circulation changes as the primary mechanism. In order to identify contributions to climatic variations resulting from both external and internal sources, both temporal and spatial scales might hold valuable information. It is crucial in this context to study the system in a framework that allows all climate components to interact and respond. Here, we use the fully coupled NCAR Paleo-CSM to present climate variation on centennial time scales as simulated in fully forced experiments of the last millennium. We compare both temporal and spatial patterns to fingerprints that would be expected from internal modes as well as from external forcing. The question is addressed if internally caused fluctuations can be systematically separated from external influences through characteristic imprints on global or hemispheric climate, and to what degree models that can be run for 1000 years can be useful, selectively, even on the regional scale.

## PP51A-04 0845h INVITED

### Statistical properties and spatial distribution of the low-frequency solar signal in paleoclimate reconstructions and a coupled model

Hee-Seok Oh[1] (1-780-492-4115; heeseok@stat.ualberta.ca)

Caspar M. Ammann[2] (1-303-497-1705)

Philippe Naveau[3] (1-303-492-4152)

R. Tomas[3] (1-303-497-1311)

F. Joos[4]

[1]University of Alberta, 114 St - 89 Ave, Edmonton, AB T6G 2G1, Canada

[2]National Center for Atmospheric Research, 1850 Table Mesa Drive, Boulder, CO 80307, United States

[3]University of Colorado, ECOT 231, Boulder, CO 80309, United States

[4]University of Bern, Sidlerstrasse 5, Bern 3012, Switzerland

New doubt raised on physical mechanisms previously assumed to be responsible for a low-frequency background trend in the solar activity has put many climate studies in a void. Both climate modeling and proxy based fingerprinting efforts are directly affected by this issue because they strongly depend on the reconstructions of the forcing for which they attempt to find characteristic signals in climate. Although large uncertainty has been known for a long time, the possible lack of a solar trend appears in sharp contrast to what was generally regarded as an already rather too small of a forcing given the magnitude of some of the climate variations over the past centuries and millennia. The new findings now put even more weight onto feedback processes that can magnify the signal. We present statistical analyses of proxies representing different solar activity measures from the last millennium. We then isolate the temporal elements of past solar activity that one would still expect to find even under absence of the stong background trend. Using non- decimated descrete wavelet transform, the spatial features of solar modulated climate variations are extracted from proxy records as well as from two experiments with a coupled General Circulation Model which were forced with solar irradiance variability and explosive volcanism. We discuss important aspects of coherency and stationarity for the known solar variations at 11/22-year, 80-88-year and 200-year cycles and quasi-cycles. Finally, we present a statistical framework which can help identify mechanisms and feedbacks involved in translating a solar modulated perturbation into the Earth's climate system.

## PP51A-05 0900h

### Solar Forcing of Polar Atmospheric Circulation: A Mechanism for Global Scale Abrupt Climate Change

Paul Andrew Mayewski[1] (207-581-3019; paul.mayewski@maine.edu)

Kirk Maasch[1] (207-581-2197; kirk@iceage.umeqs.maine.edu)

Eric Meyerson[1] (207-581-2213; eric.meyerson@maine.eud)

[1]Climate Change Institute, University of Maine 303 Bryand Global Science Ctr, Orono, ME 04469-5790, United States

Abrupt climate change events come in a variety of temporal and spatial scales ranging from the massive events of the last glacial period to the more subtle versions of the Holocene. The impact of even relatively subtle Holocene abrupt climate change events can be extremely dramatic leading to the disruption of ecosystems and human civilization. The most recent Holocene abrupt climate change event is classically referred to as the Little Ice Age. Examination of ice core records suggest that a precursor for this event may have affected Antarctica hundreds of years before the classic, globally distributed onset of the LIA in the late 14th to early 15th centuries. Comparison of several multi-centennial, sub-annually resolved, instrumentally-calibrated ice core proxy records from Greenland representing behavior of the Icelandic Low and Siberian High and from Antarctica representing behavior of the Amundsen Sea Low and East Antarctic High and a variety of proxies for solar variability offer intriguing associations. These associations validate solar-climate associations that involve changes in UV, greenhouse gases, and N compounds and consequent changes in atmospheric circulation. Set in the context of the longer term perspective provided by our ice core records, recent anomalies in the climate of the Northern and Southern Hemisphere, may be indicative of the complex involvement of natural and anthropogenic controls on climate.

## PP51A-06 0915h

### Solar vs. Anthropogenic Forcing During the Maunder Minimum

David Rind[1] (212-678-5593; drind@giss.nasa.gov); Patrick Lonergan[1] (212-678-5544; plonergan@giss.nasa.gov); Judith Lean[2] (202-767-5116; jlean@ssd5.nrl.navy.mil); Drew Shindell[1] (212-678-5561; dshindell@giss.nasa.gov); Judith Perlwitz[1] (212-678-5592; judith@giss.nasa.gov); Jean Lerner[1] (212-678-5589; jlerner@giss.nasa.gov); Chris McLinden[3] (416-739-4594; chris.mclinden@ec.gc.ca)

[1]NASA/Goddard Institute for Space Studies at Columbia University, 2880 Broadway, New York, NY 10025, United States

[2]Naval Research Laboratories, Code 7376L, Washgton, DC 20375, United States

[3]Meteorological Serivce of Canada, 4905 Dufferin Street, Downsview, Ont M3H5T4, Canada

A series of ensemble GCM experiments have been run comparing the impact of solar and anthropogenic forcing for the past 500 years. Simulations include spectrally-differentiated solar irradiance changes, a full stratosphere, and stratospheric ozone response. The results show that using a spectral vs constant wavelength change in solar forcing does not alter the overall magnitude of tropospheric cooling, although with the uniform spectral reduction there was a larger tropical response, and less stratospheric cooling. Reduced solar UV led to stratospheric ozone reduction compared to today with both the current day and pre-industrial background; however, the preindustrial composition produced stratospheric ozone increases, which led to an over total ozone increase, even during the Maunder Minimum. Using an alternate ozone photochemistry scheme (Linoz) in a higher resolution model resulted in qualitatively similar responses except that the preindustrial composition effect was somewhat smaller. The ozone changes did not have much influence on tropospheric climate, although there was some effect on high latitude pressure/height indices. With the magnitudes employed here (-0.68Wm-2 solar; -1.9Wm-2 anthropogenic) trace gas/aerosol changes produced twice as much cooling relative to today as the solar irradiance change. The cooling was much larger than that estimated in some recent temperature reconstructions, and in particular the tropical response was much larger. The NAO/AO phases were more negative with either the anthropogenic or solar-induced cooling, influenced by a reduction in the Hadley Cell intensity, and therefore do not appear to strongly discriminate between them (despite some ozone change influence). Precipitation changes followed the Hadley Cell and NAO effects, so likewise responded in a qualitatively similar manner to the two forcings. A full stratosphere was necessary to produce the negative NAO/AO response unless the cooling was sufficiently large.

## PP51A-07 0930h INVITED

### The Little Ice Age in the tropical Andes

Vincent Jomelli[1] (59-1-45-07-55-81; jomelli@cnrs-bellevue.fr)

Dan Cooley[2] (1-303-495-3610; cooleyd@colorado.edu)

Philippe Naveau[2] (1-303-492-4152; naveau@colorado.edu)

Antoine Rabatel[1] (59-1-22-77-24-59; rabatelantoine@yahoo.fr)

[1]CNRS Laboratory of Physical Geography, UMR 8591 1, Place A. Briand, Meudon-Bellevue 92195, France

[2]Department of Applied Mathematics, University of Colorado ECOT 231, Boulder, CO 80309-0526, United States

The period known as the Little Ice Age, from the 17th to the 19th century, brought a cooling of around 0.5 degrees Celsius as well as varyingly humid episodes Eurasia and North America. Because of a lack of long paleoclimatic time series in the tropical Andes, it is still unclear if similar cooling occurred over these tropical and Southern Hemisphere regions. Furthermore, if changes did take place, it is currently not well established if they were temporally synchronous or shifted with respect of the variations in the Northern Hemisphere or the globe. To look into this important climatic question and for advancing our understanding of the past climate links between the tropics and higher latitudes, 25 glaciers located in Bolivia and in Peru were carefully selected. Glacial activity and environmental changes were analyzed using lichenometry. Largest lichen diameters were measured in the different glacial basins. To better analyze these maximum diameters and to more appropriately represent uncertainty and the character of this collected data, age estimates of the different moraine systems were derived using extreme value theory rather than the traditional averaging. The results reveal two particular phases of glacier growth, 1550-1600 and 1800-1850. These two phases have also been identified in other proxy records, such as ice-cores and documentary data (particularly from church chronicles). In order to understand the climatic changes that could have contributed to the glacial variations, a simple model based on both precipitations and temperatures is applied to estimate mass balance questions in the basins. A cooling of the order of 0.5 C seems to be the most consistent with the data. Finally, these findings are compared with the better-known histories of Northern Hemisphere mid-latitude glaciers.

## PP51A-08 0945h

### Evidence of Little Ice Age in an East Antarctica Ice Core

Jihong Cole-Dai[1] (jihong_cole-dai@sdstate.edu)

Yuansheng Li[2] (yansheli@public3.sta.net.cn)

Liya Zhou[2,3] (azhouly@yahoo.com.cn)

[1]Department of Chemistry and Biochemistry South Dakota State University, Box 2202, Brookings, SD 57007, United States

[2]Polar Research Institute of China, 451 Jinqiao Road PuDong District, Shanghai 200129, China

[3]Department of Earth Sciences Nanjing University, 22 Hankou Road, Nanjing 210093, China

An 80 meter ice core was retrieved from an East Antarctica location (76°S, 77°E) by the Chinese Antarctica Research Expedition in 1999. Chemical analysis of the ice core has yielded a record of ionic impurities in snow for the past 800 years (1200-1999 A.D.). The ice core is dated using a combination of annual layer counting and volcanic time stratigraphic horizons, resulting in an accurate chronology with high resolution. The ice core record demonstrates that, during the period of approximately 1300-1850 A.D., the concentrations of several chemical species, including nitrate and methanesulfonate, are sharply lower than the levels both prior to and after this period. This period coincides with the most recent neoglacial climatic episode, the "Little Ice Age (LIA)," that has been found in numerous Northern Hemisphere proxy and historic records. Additional evidence includes the sharply reduced net snow accumulation rates during this period. The significance of this new finding will be discussed in the context of LIA evidence in Antarctica ice cores, its probable regional and spatial variations, and chronological relationships to LIA signals in South America and in the Northern Hemisphere.

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