With support from the U.S. National Science Foundation (NSF), a multidisciplinary workshop organized by the Cooperative Institute for Deep Earth Research (CIDER) was held at the Kavli Institute for Theoretical Physics of the University of California, Santa Barbara on 12 July–6 August 2004 (http://online.kitp.ucsb.edu/online/earth04/). Part of the workshop focused on the post-perovskite phase transition, and highlighted the emerging multidisciplinary challenges.

CIDER provides a promising community organization for communication and collaboration across the relevant disciplines, and the NSF Program for Cooperative Studies of the Earth's Deep Interior is a key source of research support. Special sessions recently held at the 2004 AGU Fall Meeting, and upcoming at the 2005 Joint Assembly, are another valuable means by which to inform and catalyze interactions across the community.

Acknowledgments

The authors thank Barbara Romanowicz and Adam Dziewonski for organizing the 2004 CIDER workshop, which was partially supported by NSF under grants PHY99-07949 to the Kavli Institute and EAR-0215587 to CIDER.

References

Badro, J., J.-P. Ruef, G. Vankó, G. Monaco, G. Fiquet, and F. Guyot (2004), Electronic transitions in perovskite: Possible nonconvecting layers in the lower mantle, *Science, 305*, 383–386.

Humayun, M., L. Qin, and M. D. Norman (2004), Geochemical evidence for excess iron in the mantle beneath Hawaii, *Science, 306*, 91–94.

Iitaka, T., K. Hirose, K. Kawamura, and M. Murakami (2004), The elasticity of the MgSiO$_3$ post-perovskite phase in the Earth's lowermost mantle, *Nature, 430*, 442–445.

Lay, T., E. J. Garnero, and Q. Williams (2004), Partial melting in a thermo-chemical boundary layer at the base of the mantle, *Phys. Earth Planet. Inter., 146*, 441–467.

Mao, W. L., G. Shen, V. B. Prakapenka, Y. Meng, A. J. Campbell, D. L. Heinz, J. Shu, R. J. Hemley, and H.-K. Mao (2004), Ferromagnesian postperovskite silicates in the D″ layer, *Proc. Natl. Acad. Sci. U.S.A., 101*, 15,867–15,869.

Matyska, C., and D. A. Yuen (2004), The importance of radiative heat transfer for superplumes with a deep mantle phase transition, *Earth Planet. Sci. Lett., 125*, 255–266.

Murakami, M., K. Hirose, K. Kawamura, N. Sata, and Y. Ohishi (2004), Post-perovskite phase transition in MgSiO$_3$, *Science, 304*, 855–858.

Nakagawa, T., and P. J. Tackley (2004), Effects of a perovskite-post perovskite phase change near core-mantle boundary in compressible mantle convection, *Geophys. Res. Lett., 31*, L16611, doi:10.1029/2004GL020648.

Oganov, A. R., and S. Ono (2004), Theoretical and experimental evidence for a post-perovskite phase of MgSiO$_3$ in Earth's D″ layer, *Nature, 430*, 445–448.

Shim, S.-H., T. S. Duffy, R. Jeanloz, and G. Shen (2004), Stability and crystal structure of MgSiO$_3$ perovskite to the core-mantle boundary, *Geophys. Res. Lett., 31*, L10603, doi:10.1029/2004GL019639.

Sidorin, I., M. Gurnis, and D. V. Helmberger (1999), Dynamics of a phase change at the base of the mantle consistent with seismological observations, *J. Geophys. Res., 104*, 15,005–15,023.

Tsuchiya, T., J. Tsuchiya, K. Umemoto, and R. M. Wentzcovitch (2004a), Elasticity of post-perovskite MgSiO$_3$, *Geophys. Res. Lett., 31*, L14603, doi:10.1029/2004GL020278.

Tsuchiya, T., J. Tsuchiya, K. Umemoto, and R. M. Wentzcovitch (2004b), Phase transition in MgSiO$_3$ perovskite in the Earth's lower mantle, *Earth Planet. Sci. Lett., 224*, 241–248.

Author Information

Thorne Lay, University of California, Santa Cruz; Dion Heinz, University of Chicago, Ill.; Miaki Ishii, Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California, San Diego; Sang-Heon Shim, Massachusetts Institute of Technology, Cambridge; and Jun Tsuchiya, Taku Tsuchiya, Renata Wentzcovitch, and David Yuen, University of Minnesota, Minneapolis

For additional information, contact T. Lay; E-mail: thorne@pmc.ucsc.edu.

New Approaches for Extending the Twentieth Century Climate Record

PAGES 2,6

Studying twentieth century climate is a key to understanding future climate change. Relatively little is still known, however, about climate variability in the first half of the century. Much could be learned from the relatively large climatic variations that occurred during that first half, including the decade-long "Dust Bowl" droughts of the 1930s and the warming of the Arctic from 1920 to 1945.

Poor digital data availability prior to around 1948 has hindered previous work to understand these important climatic variations.

Several projects now are focusing on digitizing earlier manuscript observations to create three-dimensional, gridded meteorological data sets for the first half of the twentieth century. These data sets are likely to provide further insights into processes governing interannual-to-interdecadal large-scale climate variability.

Meteorologists, geophysicists, navy pilots, ship crews, and numerous volunteer observers collected enormous amounts of atmospheric data in the first half of the twentieth century, sometimes under extreme and dangerous conditions. A large fraction of these data, especially upper air data, never made the transition to the "modern era" of climatology, which started after World War II. The reasons are manifold and include military secrecy; interrupted international collaboration; political and institutional changes during and following the war; and, sometimes, simply neglect.

Yet, these data can still be found today on paper in various meteorological archives. With new numerical and statistical techniques becoming available, these archives now could be fruitfully mined for climate research.

Data availability is comparably good for meteorological observations at the Earth's surface, which have been used continuously to study past climate variability. Several ongoing projects are increasing the data quality and quantity [e.g., *Worley et al.*, 2005]. Surface data, however, do not suffice to fully understand the mechanisms governing large-scale climate variability.

Upper air data are needed for accurate descriptions of important dynamical features such as the positions of the jet streams, the planetary wave structure, and the strength of the stratospheric polar vortex. Yet, gridded upper air data sets currently are available only for the second half of the twentieth century; they are based largely on radiosonde data, and since 1973, on radiosonde and satellite data (Figure 1).

Although the notion is widespread among climate scientists that there were no operational upper air measurements before about 1948, this is not the case (Figure 1). Radiosonde observations have been made since the mid-1930s. Prior to the radiosonde era, weather balloons with graphical registering devices were used. Even more common were kite soundings or aircraft measurements up to 4 or 5 km altitude. Pilot balloons have been launched routinely since the early twentieth century to obtain information on upper level winds. In addition to meteorological measurements, spectrographical total ozone observations reaching back to the 1920s can be used to derive indirect information on stratospheric dynamics.

The total amount of data is small by current standards, but it is non-negligible. It is estimated that several million pilot balloons were launched prior to 1948, and there were several hundred thousand radiosonde ascents and aircraft flights (Figure 1).

Significant fractions of these data are currently being digitized and processed by organizations such as the U.S. National Climate Data Center (NCDC), the National Center for Atmospheric Research (NCAR), and the World Data Center (WDC) for Meteorology in Obninsk, Russia. Additional work is done by scientists at the Swiss Federal Institute of Technology (ETH) Zürich in the framework of a Swiss National Science Foundation project led by the first author.

Re-evaluating historical upper air data is demanding work. After digitizing the numbers from paper, the data need to be corrected for various instrumental errors, a task made difficult by the lack of good background information.

By S. Brönnimann, G. P. Compo, P. D. Sardeshmukh, R. Jenne, and A. Sterin

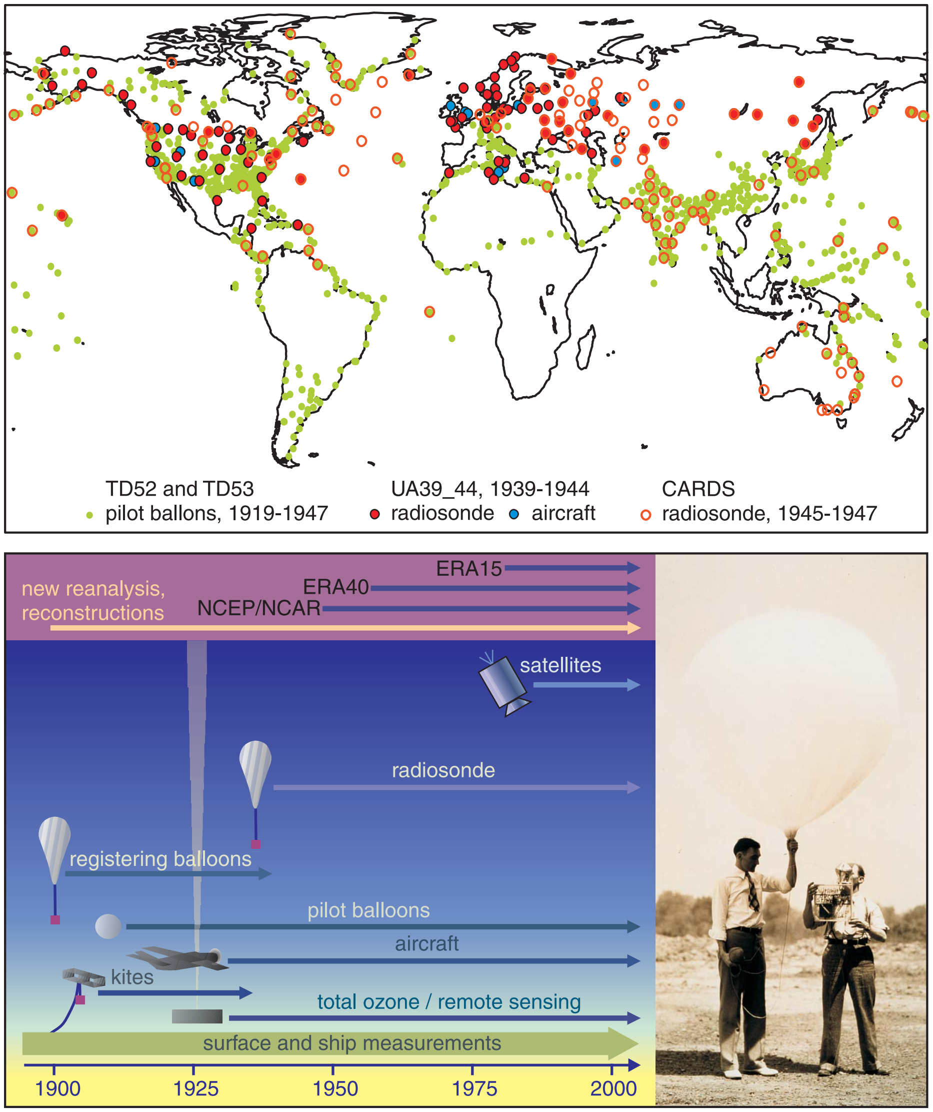

*Fig. 1. (top) Upper air data prior to 1948 that is currently available in digital format from the data sets TD52 and TD53 (NCAR, http://dss.ucar.edu/docs/papers-scanned/papers.html, documents RJ0167, RJ0168), UA39_44 [*Brönnimann*, 2003], and CARDS (Comprehensive Aerological Reference Data Set) (http://www.ncdc.noaa.gov/oa/climate/cards/cards_homepage.html). (bottom left) A schematic of the types of upper air and surface observations performed during the twentieth century. The top part shows the currently available and planned gridded upper level data sets. (bottom right) Launch of radiosonde at Washington Airport, Washington, D.C., 7 May 1936 (source: National Oceanic and Atmospheric Administration Photo Library, U.S. Department of Commerce).*

In fact, even for the second half of the century, where such information is available, the quality of radiosonde data remains a major challenge, for example, when attempting to correct for changes in instruments and practices [e.g., *Lanzante et al.*, 2003].

Despite these problems, preliminary results [*Brönnimann*, 2003] suggest that useful upper-air information for the extratropical Northern Hemisphere could be obtained back to around 1925.

From Point-Data to Three-Dimensional Grids

Several approaches can be used to derive gridded spatial fields from this information. Data assimilation combines a statistical filtering technique together with background information from a numerical weather prediction model to yield a physically consistent, "optimal" representation of the data every few hours. Such reanalysis data sets are the standard in atmospheric research today, the most important examples being NCEP-NCAR Reanalysis and the European Centre for Medium-Range Weather Forecast Reanalysis Projects ERA15 and ERA40 (see Figure 1).

Because much less data are available in the pre-reanalysis period (prior to 1948), an assimilation of historical data is not expected to provide the same quality product as current data sets. However, more powerful assimilation schemes optimized for sparser observations can be used.

At the Climate Diagnostics Center (NOAA-CIRES [Cooperative Institute for Research in Environmental Sciences, sponsored jointly by NOAA and the University of Colorado, Boulder]/CDC) in Boulder, Colorado, new techniques such as the "ensemble square root-filter" (EnSRF) [*Whitaker and Hamill*, 2002] have been developed and tested. Figure 2 shows Northern Hemispheric 500-hPa (hectopascals) geopotential height fields for 14 December 2001, 0000 UTC, obtained from a conventional assimilation of all available data (surface, upper air, and satellite; left panel), and an EnSRF assimilation using only a limited number of surface pressure observations (right panel), mimicking the network of land stations and marine observations of the year 1915 (black dots) [*Whitaker et al.*, 2004].

The two fields are very similar; their difference (the error of the "reanalysis") is of comparable magnitude to current 2.5-day forecast errors. Overall, the results of Whitaker et al. suggest that useful upper air circulation analyses up to the middle troposphere may already be feasible with the available digitized data, even for times prior to any upper air observations.

Better results could be expected if historical upper air data were also to be included. The goal of the efforts at NOAA-CIRES/CDC is to produce a new reanalysis data set for the entire twentieth century to present.

Another approach to deriving fields from scattered upper air observations is reconstruction, i.e., by using statistical relationships derived from the modern era. The technique has been widely used in climate research to reconstruct surface fields on a monthly to annual scale [*Luterbacher et al.*, 2004].

Statistical reconstruction is much simpler and less costly than data assimilation, but does not have the ability to represent high-resolution features. Nevertheless, relatively good quality monthly fields of temperature and geopotential height up to 100 hPa have recently been reconstructed for the extratropical Northern Hemisphere back to 1939 [*Brönnimann and Luterbacher*, 2004].

As an example, 300-hPa geopotential height anomalies for March 1941 are shown in Figure 3 together with the upper air stations used for the reconstruction. In view of these results, the data now being digitized are expected to yield reliable reconstructions up to the upper troposphere, and regionally even up to the lower stratosphere, back to the mid-1920s.

It is hoped that the new upper air data sets and improved surface data, which will become available within the next few years, will lead to a better understanding of important climate variations such as the Dust Bowl [*Schubert et al.*, 2004] of the 1930s, the global climate anomaly of the early 1940s, and the Arctic warming from 1920 to 1945 [*Polyakof et al.*, 2003]. In conjunction with the already available reanalysis data sets for the second half of the twentieth century, they will offer a new look at climate variability during the entire century.

The authors appreciate contributions by members of the AGU community. *Eos* readers having information on pre-1948 upper air observations, stations, instruments, calibration,

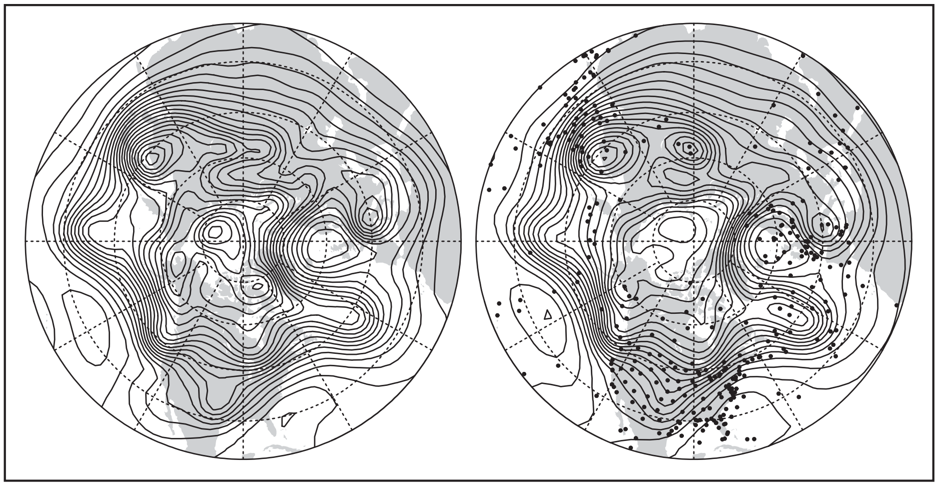

Fig. 2. A 500-hPa geopotential height analysis for 14 December 2001, 0000 UTC (contour interval are 50 m). The NCEP-NCAR Reanalysis using all available observations is shown on the left. The EnSRF analysis using the simulated 1915 surface pressure observations network (black dots) is shown on the right (reprinted from Whitaker et al. *[2004], Copyright 2004 American Meteorological Society). The root mean square difference between the left and right panels is 33 m, and the anomaly pattern correlation is 0.96.*

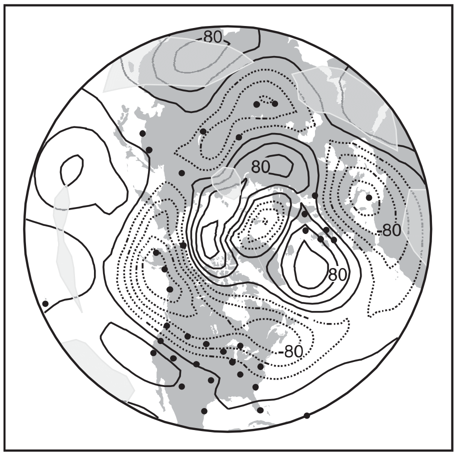

*Fig. 3. The 300-hPa geopotential height anomalies (in geopotential meters, with respect to 1961–1990) for March 1941, obtained from statistical reconstructions [*Brönnimann and Luterbacher, *2004]. Black dots mark the upper air stations used in the reconstructions (in addition to upper-air data, 100 surface temperature series as well as sea level pressure fields were used). Lighter shaded areas denote a low reconstruction skill (RE < 0.2) [see* Brönnimann and Luterbacher, *2004].*

technical details, measurement and reporting procedures, etc., are invited to contact the first author: broennimann@env.ethz.ch.

References

Brönnimann, S. (2003), A historical upper-air data set for the 1939-1944 period, *Int. J. Climatol., 23*, 769–791.

Bronnimann, S., and J. Luterbacher (2004), Reconstructing Northern Hemisphere upper level fields during World War II, *Clim. Dyn., 22*, 499–510.

Lanzante, J. R., S. A. Klein, and D. J. Seidel (2003), Temporal homogenization of monthly radiosonde temperature data: Methodology, *J. Clim., 16*, 2224–2240.

Luterbacher, J., D. Dietrich, E. Xoplaki, M. Grosjean, and H. Wanner (2004), European seasonal and annual temperature variability, trends and extremes since 1500, *Science, 303*, 1499–1503.

Polyakof, I. V., et al. (2003), Variability and trends of air temperature and pressure in the maritime Arctic, 1875-2000, *J. Clim., 16*, 2067–2077.

Schubert, S. D., M. J. Suarez, P. J. Pegion, R. D. Koster, and J. T. Bacmeister (2004), On the causes of the 1930s Dust Bowl, *Science, 303*, 1855–1859.

Whitaker, J. S., and T. Hamill (2002), Ensemble data assimilation without perturbed observations, *Mon. Weather Rev., 130*, 1913–1924.

Whitaker, J. S., G. P. Compo, X. Wei, and T. M. Hamill (2004), Reanalysis without radiosondes using ensemble data assimilation, *Mon. Weather Rev., 132*, 1190–1200.

Worley, S. J., S. D. Woodruff, R. W. Reynolds, S. J. Lubker, and N. Lott (2005), ICOADS Release 2.1 data and products. *Int. J. Climatol.*, submitted.

Author Information

S. Brönnimann, ETH Zurich, Switzerland; G. P. Compo and P. D. Sardeshmukh, NOAA-CIRES CDC, Boulder, Colo.; R. Jenne, NCAR/UCAR, Boulder, Colo.; and A. Sterin, Research Institute of Hydrometeorological Information-World Data Centre, Obninsk, Russia

---

Did the 26 December 2004 Sumatra, Indonesia, Earthquake Disrupt the Earth's Rotation as the Mass Media Have Said?

PAGES 1–2

The answer to this question is a definite yes. But then again, the same is true of any earthquake, large or small, or for that matter of any worldly event that involves mass transport, from atmospheric and ocean seasonality, to melting of glaciers and tropical storms, to a bus driving around town. All one needs to convince oneself of this is to invoke the conservation of angular momentum and apply it to the Earth system.

The real question should be, Did this particular earthquake disrupt the Earth's rotation to a level large enough to be noticeable, or, technically, observable? The answer is a sobering hardly, but at the same time very exciting in scientific implications.

Following *Chao and Gross* [1987; see also *Chao and Gross*, 2000], we have been routinely calculating earthquakes' coseismic effects in changing the Earth's rotation (in both length of day (LOD) and polar motion) as well as the low-degree gravitational field. The algorithm uses the normal-mode summation scheme by inputting the Harvard centroid-moment tensor solution (courtesy of http://www.seismology.harvard.edu/CMTsearch.html), which represents the magnitude and focal mechanism of a given earthquake. The results are reported and updated on the Web site of the Special Bureau for Mantle of the International Earth Rotation and Reference Systems Service's (IERS) Global Geophysical Fluids Center (http://bowie.gsfc.nasa.gov/ggfc/mantle.htm/). Currently included are 21,600 major earthquakes worldwide with magnitude greater than 5 since 1977.

Their cumulative, coseismic geodynamic effects show intriguing long-term trends for geophysicists to ponder. For instance, the earthquakes collectively have an extremely strong tendency to make the whole Earth rounder and more compact in all directions, shortening LOD. They have also been nudging the mean North Pole position toward the direction of ~140°E. However, they did these so very slightly that the resultant signals have so far eluded detection, even with today's space geodetic technique capabilities. Worse still, these signals were buried in other signals that are orders of magnitude larger resulting from various other geophysical and climatic causes occurring all the time.

This was the case at least up until recently. Previously, however, there had been two gigantic earthquakes in the 1960s that had also been geophysically modeled, namely, the 1960 Chilean event and the 1964 Alaskan event. They should have caused geodynamic changes that were large enough to be detected under today's observational capability, which was of course lacking at the time. For example, the Chilean earthquake should have shifted the North Pole toward ~115°E by about 23 mas, corresponding to ~70 cm, compared with today's subcentimeter measurement precision. The corresponding change in LOD, on the other hand, was only about -8 microseconds (μs), a few times below today's detection level. The Alaskan earthquake should have changed the Earth's oblateness J_2 by $+5.3 \times 10^{-11}$, which would take the postglacial rebound 2 years to "iron out," compared with today's detectability level