Cooperative Institute for Research in Environmental Sciences

CIRES

Annual Report

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Director's Welcome

Greetings! In the following pages you will find a summary of some of the exciting research that was accomplished last year in the Cooperative Institute for Research in Environmental Sciences (CIRES). There is something for everyone: from earthquakes to geomagnetic storms and everything in between, the institute thrives on its Earth System Science approach. I encourage you to take a moment to read about our activities this past year.

It is difficult to highlight any one area of research, so I won't attempt to do so. However, one of the major new programmatic opportunities, our Innovative Research Program, has stimulated creative thought throughout the institute, even more than usual. This program has provided support for seeding or testing high-risk new ideas. Often these ideas are for a novel approach to a new idea or an instrument requiring proof-of-concept. Other projects have focused on unique opportunities to enhance or integrate new data sources for research or decision-maker use. New conceptual models have been designed and experiments proposed that stretch our imaginations beyond what we already understand about the complexities of the earth system. Many of these projects were recently highlighted at a CIRES poster session. It was fun!

While putting together this annual report, I was reminded that earth system science forges international collaborations, probably more than any other science. We do field work in many other countries, on the oceans, and in space. We have developed strong ties with colleagues and friends, and have experienced the wonders of many cultures. Our observations, models, and theories help understand the many relationships within our environment, including the interactions with humans. This interconnectedness is global and is important as we recover from the events of September 11, 2001.

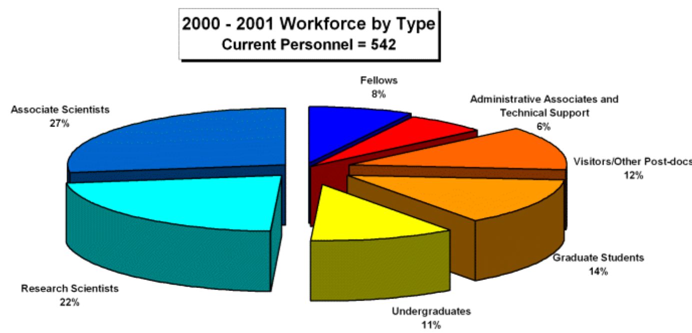
I thank the University of Colorado at Boulder and the National Oceanic and Atmospheric Administration for their continued support in a partnership that continues to grow and allows us to facilitate interdisciplinary research. It has been a rewarding year.

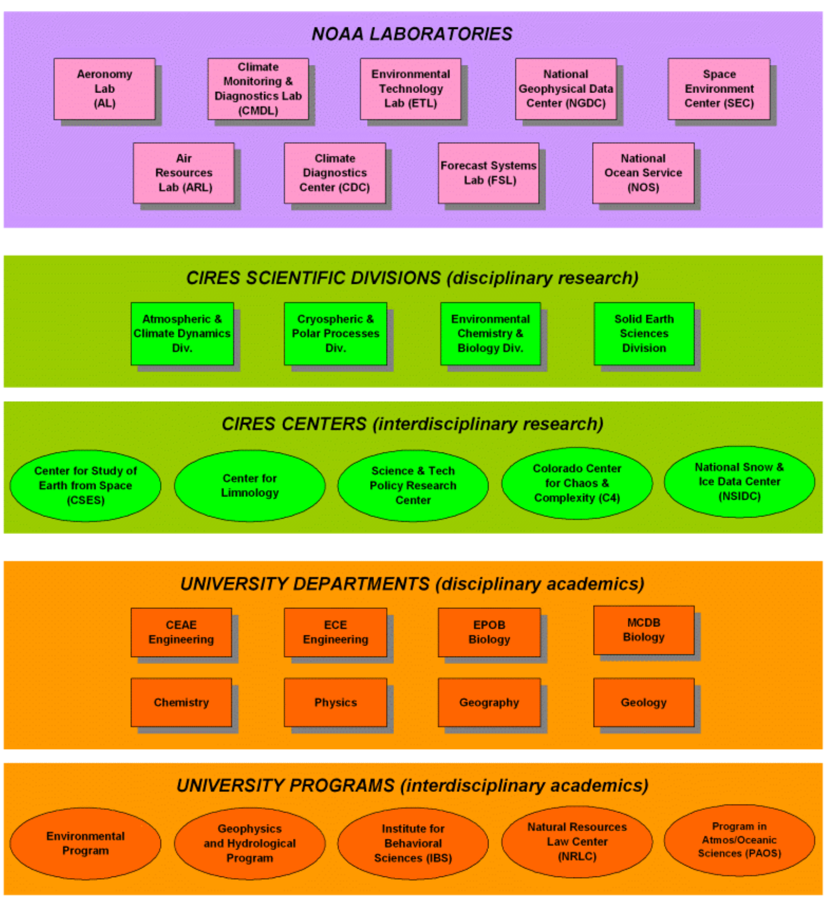
Susan K. Avery

Overview of CIRES

The Cooperative Institute for Research in Environmental Sciences (CIRES) is a joint institute established nearly 35 years ago between the University of Colorado and the National Oceanic and Atmospheric Administration (NOAA) to create a synergy between studies of the geosphere, biosphere, atmosphere, hydrosphere and cryosphere. CIRES is a unique bridge that provides the mission-oriented NOAA laboratories access to an academic diversity that it does not itself possess. It provides and strengthens the scientific foundation upon which NOAA's many services depend. CIRES' connections with NOAA's office of Oceanic and Atmospheric Research (OAR) and sister joint institutes also provide an avenue for coordinated studies on a scale that could not be addressed by academic departments on their own.

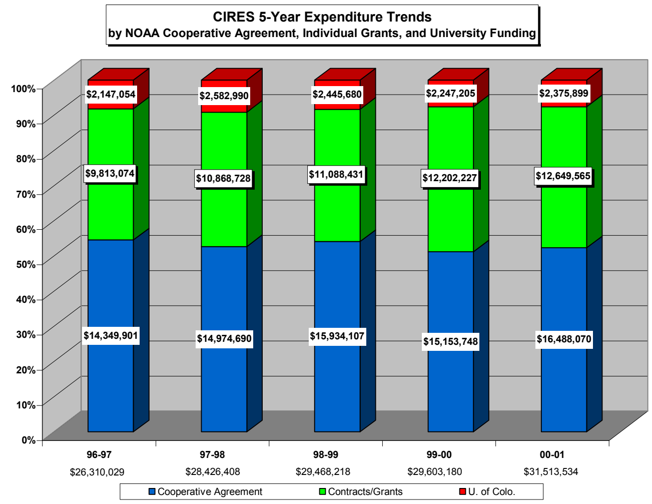
CIRES is comprised of approximately 550 researchers, faculty, students, and staff housed in the David Skaggs Research Center and on campus. About half of our personnel fill scientist positions, and more than a quarter consist of undergraduate and graduate student positions. CIRES maintains an active visiting fellow program and recently created a new Research and Education Fellowship to promote the academic component of our outreach program.

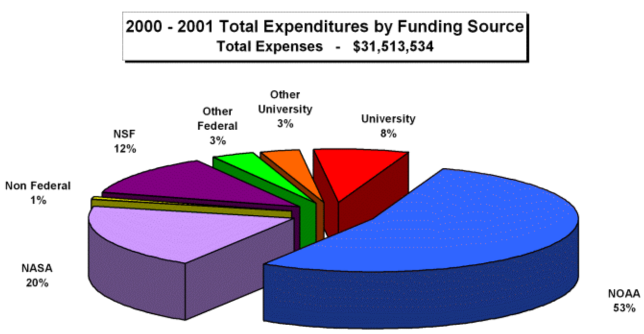




Traditional disciplinary research is conducted through a broad range of academic departments and the nine local NOAA laboratories. Interdisciplinary science is fostered through centers that cross traditional boundaries and include the *Center for the Study of Earth from Space*, the *Center for Limnology*, the new *Science & Technology Policy Research Center*, the *Colorado Center for Chaos and Complexity*, and the *National Snow and Ice Data Center*. CIRES' campus affiliation provides NOAA a breadth of connections such as the Natural Resources Law Center that forms a unique component of the Western Water Assessment.

CIRES direction is provided through the Council of Fellows, an active Executive Committee, and committees working on focused objectives (such as maintaining computing facility excellence). *Communication* is facilitated through a Members' Council, scientific retreats, regular town meetings, and an active outreach effort. *Career progression and excellence* are promoted through a Career Track and Outstanding Employee Recognition Program. A vibrant *academic and research environment* is fostered through a Graduate Research Fellowship Program, a Visiting Faculty and Postdoctoral Program, an Innovative Research Program, an Interdisciplinary Lecture Series, and research initiative seed funding. *Advanced research tools* are provided through an instrument design group, machine shop, glassblowing, numerical climate models, and access to various tools such as remote sensing instrumentation. Other *support* includes a computing facility, specialized software tools (such as Geographic Information System [GIS] and statistics), auditorium, and classrooms fitted with audio visual tools. NOAA *funding* is allocated among three Tasks including administrative support base funding (Task I), National Snow and Ice Data Center (Task II) and scientific research (Task III).

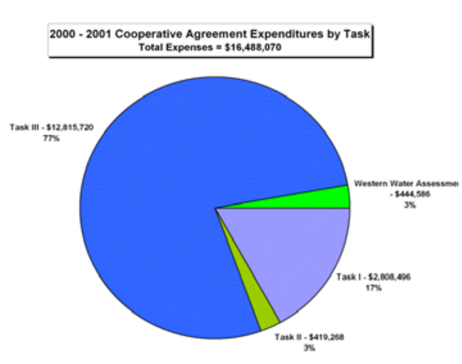


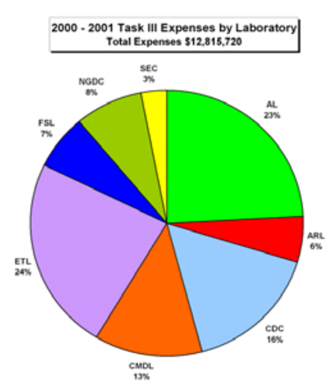


The charts on this page provide a breakdown in funding trends, sources by agency, and a breakdown by NOAA Tasks. The latter remains our largest funding source and includes research and base funds. The CU funding includes faculty salaries, indirect cost recovery, and non-research general fund support. CIRES is fortunate also to be able to support two types of funding programs, one for scientific visitors, and one for graduate students.

CIRES research programs have recently involved field investigations in the Arctic and Antarctic regions, the Himalayas, South America, various Pacific islands as well as research sites throughout the United States. Results of this research bear upon societal problems such as the potential impacts of climate change upon watersheds, pollutant destruction of Earth's ozone, the thinning of polar ice, the degradation of air and water quality, and earthquake prediction.

CIRES is increasingly providing vision and leadership in conducting highly interdisciplinary research where results are presented in a context that can be utilized by decision makers. The Western Water Initiative is just such an effort that is addressing the potential impact of climate variability





on the availability, quality, and allocation of scarce water in the rapidly populating areas of the arid interior west. It is building mutually beneficial partnerships between public and private sector users of information to determine what tools are available, can be adapted, or should be developed to assist in the utilization of a growing body of climate information. CIRES has also been an active partner with the four other Regional Integrated Science Assessments (RISA) supported by the NOAA Office of Global Programs.

The CIRES Outreach Program/Earthworks: Geoscientists Contributing to K-12 Science Education

"As a society, we cannot separate our goal to be a leading economic competitor from our duty and responsibility to educate all youngsters. This will be as clear a case of cause and effect as any we could imagine." Rita Colwell, NSF Director

Increasingly scientists are being asked to contribute to societal concerns in addition to their contributions to scientific knowledge. In education, these concerns include the need to promote diversity among scientists, to educate a competitive work force, and to have a public capable of decisions informed by science. Moreover, many funding agency programs now include public outreach as a review criteria in securing research funding.. The CIRES Outreach Program provides effective opportunities for CIRES to contribute to K-12 education, through work with school districts, outdoor education centers, teachers and the community. We provide education support for grant proposals, support researchers' education efforts, and contribute to the field of outreach through sponsored social science research. CIRES scientists and outreach staff work in school district systemic reform, teacher education, museum and informal education, science competitions, and teacher professional development.

"Earthworks" is an example of CIRES professional development for teachers, a field-based workshop for secondary science teachers from across the nation. During Earthworks, new teachers work with scientists and master teachers to design and conduct research projects suitable for implementation with students. Teachers learn to see a site "through a scientists' eyes", learn field work skills, receive guidance in designing research projects and access the support of scientists and master educators as they implement their classroom plans. We include many teachers serving disadvantaged and under-represented populations in reservation, rural and urban school settings (25-28 participants/year). We extend our impact by including district science coordinators, requiring participants to provide training for colleagues, and including staff from outdoor education centers. A spin-off project transfers science conducted during Earthworks to our host environmental education center as a contribution to their land management tools and to their programs for disadvantaged school groups.

Summary of Research Highlights

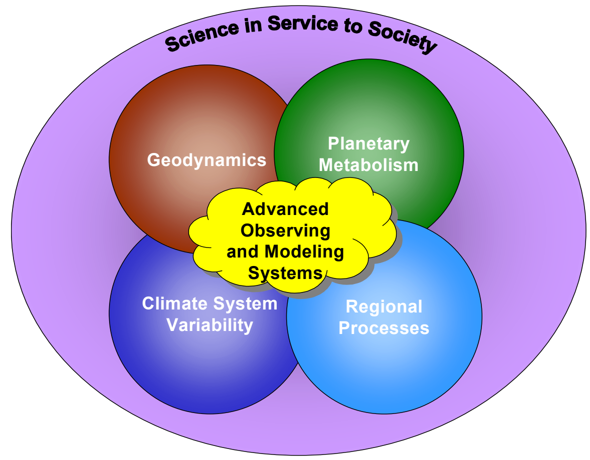
The vast array of research activities within CIRES is difficult to summarize in a comprehensive way. Certain common threads of research outcomes, however, can be deduced. This year the research has supported the IPCC and National Assessment activities as well as contributing towards an understanding of global climate change with potential implications for evolving policy alternatives. A strong emphasis has been placed in CIRES on the Arctic climate system as well as on climate variability impacts in the Interior Western United States. Atmospheric measurements of trace gases and their implications for air quality have also had a high priority in CIRES research. Continued development of databases that enhance access to decision-makers and researchers has been done for atmospheric trace gas flux measurements, oceanographic data, and spatially referenced data for air quality studies. New and enhanced observing technologies continue to be developed.

The following bullets highlight some of the research accomplishments during this last year. Specific details of this research can be found in Section V.

- Verification and diagnostics in support of IPCC and National Assessment activities
- Development of international implementation plan for the WCRP Cryosphere and Climate Project
- Use of science and experiential knowledge in understanding
    - Climate change in the Eastern Canadian Arctic
    - Impacts on climate in the Alaskan north-slope coastal region
    - Climate impacts on South Platte river basin in the Interior West
- Quantification of cooling trends in the lower stratosphere
- Identification of mid-troposphere temperature regulation mechanism in the Arctic
- Verification of earlier snowmelt timing in the Arctic associate from climate change
- Analysis indicating 50 km advance of ice sheet in Greenland during last 3000-4000 years
- Analyses showing how changes in distribution of oceans and continents affect climate
- Analysis of impacts during ENSO events on sub seasonal atmospheric variability
- First survey measurements of Russian and Chinese emissions of ozone-depleting substances
- Demonstration of impacts on air quality due to size and location of power plants
- Analysis of pollutants indicating role of nocturnal long-range transport
- Conceptual model and experiment design for testing new hypotheses on the role of organic atmospheric aerosols with implications for understanding the transport of organic material in the current and prebiotic atmospheres
- Improved modeling of budgets of trace gases for climate studies
- Role of enzyme pathways for degradation of xenobiotic compounds
- Quantification of diurnal rainfall climatology over complex terrain
- Downscaling of hydrologic variability for application in hydrologic predictions

- Improved knowledge of earthquake hazards through analysis of fault systems in New Zealand, India, and southern California
- Dataset development for
  - Flux data input into regional and global climate models
  - Higher access to oceanographic data
  - Integrated maps of data for Western Water Assessment
- Prototype studies for satellite-based wind measurements from a Doppler lidar
- Automated weather station network implementation for climate studies on the Greenland ice sheet
- New visualization techniques for improved mapping and characterization of ice sheets and sea ice
- Enhancement of radar performance and use of tethered platforms for atmospheric turbulence measurements
- Quantification of use of tropical wind profiler data in NCEP/NCAR reanalysis products
- Studies leading to potential improvements in radar rainfall estimation
- New technology for producing and drying fine particles with intended use in new drug delivery systems
- New method for analysis of biogenic volatiles that are indicators of biomass burning
- Improvement in space-weather forecasting models due to electric-field variability impacts on the energy budget in the thermosphere
- Geomagnetic storm modeling for HF communication user needs

Research Themes



As a step toward facilitating more integration of its multi-faceted research agendas, CIRES recently began coordinating its research efforts toward specific scientific objectives by adopting a set of scientific themes. We are addressing questions of scientific and societal relevance to present useful results in a meaningful context. In preparation for this change, CIRES held a series of meetings and a scientific retreat where Fellows, faculty and scientists deliberated on how this could be done and what themes should identified. This approach is decidedly more difficult than traditional hierarchical structures, but it represents a change in thinking that will translate into improved integration between disciplines and groups. It will also allow CIRES to be more adaptive in how it responds to changing scientific priorities and national imperatives.

The five themes identified were *Climate System Variability, Regional Processes, Planetary Metabolism, Geodynamics* and *Advanced Observing and Modeling Systems*. The last theme encompasses areas where CIRES has particular expertise in the development and design of various techniques that can be applied to many different disciplines. These themes are intended to integrate with and complement our existing scientific divisions that include *Atmospheric & Climate Dynamics* (ACD), *Cryospheric & Polar Processes* (CPP), *Environmental Chemistry & Biology* (ECB) and *Solid Earth Sciences* (SES).

There is clearly much overlap between the themes, but this is an inescapable result of highly integrated objectives. The original ACD and CPP divisions map primarily to the new Climate System Variability and Regional Processes themes. The previous ECB division is closely related to Planetary Metabolism and the SES division is an obvious close match with Geodynamics. All of the previous divisions have connections with the new Advanced Observing and Modeling Systems theme. We are retaining the divisional structure to enable administrative continuity, but will be encouraging this theme orientation with a series of summary documents, seminars and the identification of research foci of the year within themes.

Research Theme: *Climate System Variability*

Climate variability affects virtually all natural systems and human activities. Direct impacts of climate include such vital areas as agriculture, water quantity and quality, ecosystems, and human health. Understanding, and potentially predicting, climate changes is therefore critical to the public, as well as a broad array of decision-makers within federal and state government, industry, resources management and hazard mitigation. Indeed, basic issues include determining whether observed changes may be attributable to either natural or anthropogenic forcing, and the extent to which natural and human-induced changes may be linked. Fundamental problems include: 1) detection and description of climate changes; 2) identification of causes (attribution); and 3) prediction, which is intrinsically probabilistic in nature. Prediction problems of vital importance include estimating changes in the likelihood of extreme events, and identifying risks for abrupt climate change, because the potential for major societal and ecosystem impacts is likely to be particularly large in such cases. The following are examples of the questions being addressed in areas of established CIRES expertise.

1. Detection of climate modes, trends, and variability

The goal is a better understanding of the structure and range of natural climate variability, to help, among other things, in distinguishing it from anthropogenic climate change. This is particularly important since the power spectra of the major modes of climate variability such as ENSO, the NAO, and the Arctic and Antarctic "oscillations" are difficult to distinguish from noise at the lowest frequencies.

2. Mechanisms and forcings of climate variability

To what degree is tropical Pacific Ocean variability, or ENSO, the basic cause of all natural climate variability from seasonal to decadal scales? Are the pronounced changes in the Arctic environment observed over the past several decades a reflection of natural variability or human influences? To what extent is the cryosphere a driver of climate variability?

3. Stratospheric Ozone Depletion

To what extent are changes in the stratospheric ozone layer affecting the stratospheric thermal and wind structure, and hence wave propagation characteristics which may in turn influence tropospheric structure and climate?

4. Prediction of climate variability

To what extent does the longer memory of the deep ocean, and/or changes of sea ice, contribute to atmospheric predictability on decadal and longer scales? Are fully coupled ocean-atmosphere-cryosphere-land surface models likely to lead to significant further improvements in climate prediction? What is best way to utilize probabilistic predictions?

5. Development of extreme events and rapid climate change

To what extent are extreme anomalies and events predictable? What is the likelihood of abrupt climate change, for example, the collapse of the thermohaline circulation, and what would be the global and regional manifestations of such a change? How can we improve our use of the paleoclimate record to detect extreme events and measure their frequency?

World Climate Research Programme (WCRP) Cryosphere and Climate (CliC) Project

Project Personnel: Roger G. Barry

Theme(s): Climate System Variability

Payoff: International scientific coordination of polar climates

Funding Sources: WMO

Following three years of effort by the WCRP Arctic Climate System Study (ACSYS) project and a task group co-chaired by Roger Barry and Ian Allison, CRC, Hobart, a 15-year project to investigate the role of the cryosphere in the climate system was approved in March 2001 by the Joint Scientific Committee of the WCRP.

The cryosphere is that portion of the climate system consisting of the world's ice sheets, ice shelves, ice caps and glaciers, sea ice, seasonal snow cover, freshwater ice, and seasonally frozen ground and permafrost. The interactive role of the cryosphere in the climate system is well recognized but, with the notable exception of the Arctic Climate System Study (ACSYS), investigations of cryospheric processes are generally outside the framework of the WCRP. CliC will provide a global programme focusing on the role of the cryosphere in the climate system. It aims to fill the serious gaps in the observations, process studies and modeling of cryospheric elements, the study of cryosphere-climate interactions, their variability, change, and associated impacts.

The goals of CliC are to:

- improve understanding of the physical processes and feedbacks through which the cryosphere interacts within the climate system,
- improve the representation of cryospheric processes in models,
- assess and quantify the impact of past and future climatic variability and change, on decadal-to-century time scales, components of the cryosphere and their consequences, and
- enhance the observing and monitoring of the cryosphere.

The principal scientific questions to be addressed are:

1. How stable is the global cryosphere?
2. What is the contribution of land ice changes to global sea level?
3. What changes in frozen ground regimes can be anticipated, either directly or through feedbacks on the climate system?
4. What will be the nature of changes of sea ice mass balance in both polar regions?
5. What is the likelihood of abrupt climate changes as a result of ice shelf - or sea ice - ocean interactions that impact the ocean thermohaline circulation?
6. What will be the magnitudes and rates of change, and the seasonal redistribution in water supplies from snow and ice-fed rivers under future climate changes?

The CliC Science and Coordination Plan was published by WCRP (Allison, Barry, and Goodison, eds, WCRP 114, 2001) and is available at: http://clic.npolar.no

Regulation of Mid-Tropospheric Temperatures in the Arctic

Project Personnel: T Chase, B. Herman, R. Pielke Sr., X. Zeng

Theme(s): Climate System Variability

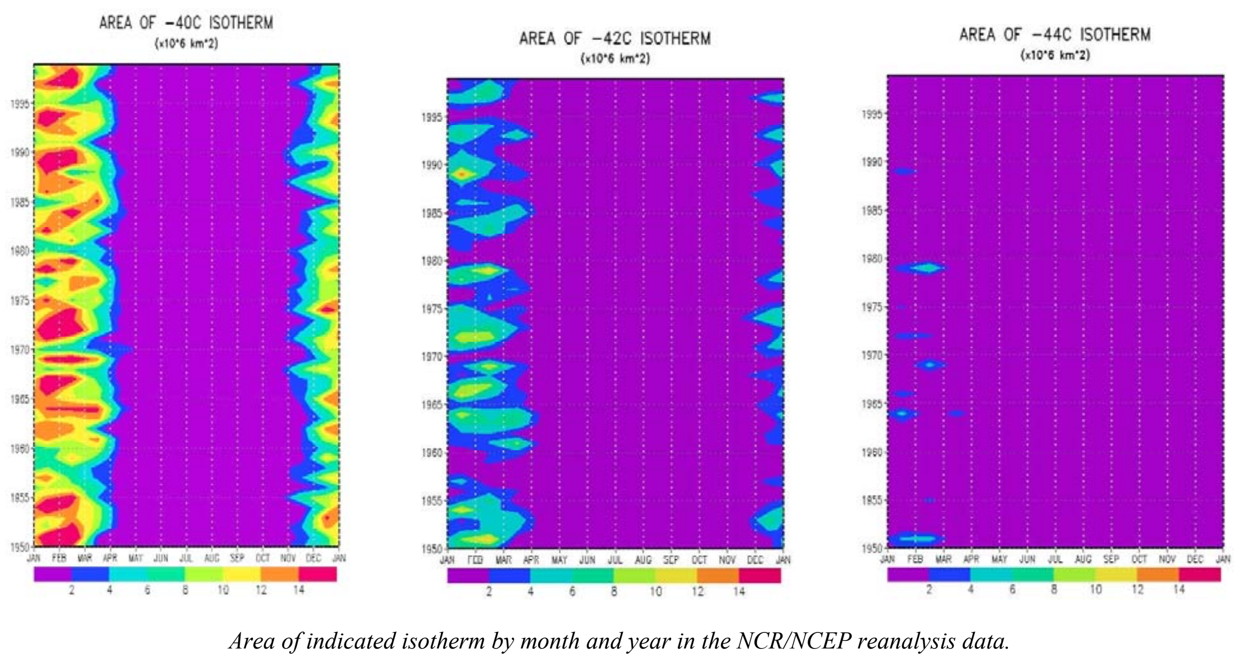
Payoff: Improved understanding of feedbacks regulating Arctic Climate.

Funding Source: CIRES Innovative Research Program

The figure below shows changes in the monthly averaged area of the -40C, -42C and -44C, 500mb isotherm between approximately 60 and 90N since 1950. The main features, which stand out from Figure 1 are that Arctic temperatures begin falling below -40C usually by November. At temperatures much below -40C, the overall area covered by the isotherm in question decreases precipitously. For example, the area of the -42C isotherm is substantially smaller than the -40C isotherm while the area covered by the -44C isotherm approaches zero in all years. Seldom, during these months, do any points reach below -45C and never during this time period was there a value less than -46C in the monthly average. Because the -40C threshold is typically first exceeded in late fall (November) it might be expected that much colder values would be reached in December, January or February when solar heating is at a minimum. As demonstrated in Figure 1, this is not the case indicating a relatively consistent control over mid-tropospheric temperature during this season.

Interestingly, this observed lower limit of approximately -40 to -45C is in the range of what would be predicted for an atmosphere in moist adiabatic equilibrium with a surface temperature at, or slightly below, 0C. For example, at -2C, the approximate absolute minimum temperature of an unfrozen sea surface during winter, the 500mb temperature resulting from moist adiabatic ascent from the surface is slightly below -45C. This is the observed annual lower limit in the monthly averaged data. This limit is also documented in daily sounding data in the Arctic.

This regulatory mechanism is, by itself, of interest and requires further documentation and comparison with model simulations. Furthermore, this mid-tropospheric temperature regulation may also have implications for surface temperature trends in the Arctic winter, a region and season where accelerated warming trends are simulated by greenhouse gas model scenarios.



Area of indicated isotherm by month and year in the NCR/NCEP reanalysis data.

Temperature Trends in the Tropical Lower Stratosphere

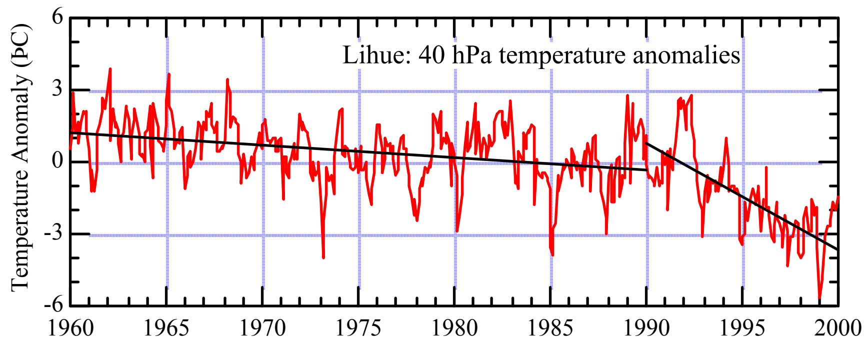
Project Personnel: G.C. Reid

Theme: Climate System Variability

Payoff: Increased understanding of factors affecting global climate change.

Decreases in ozone concentration and increases in the concentration of greenhouse gases such as carbon dioxide and methane are both expected to cool the stratosphere, through decreased absorption of solar ultraviolet and terrestrial long wave radiation in the case of ozone, and through increased outward radiation to space in the case of the greenhouse gases. A study of long-term changes in temperature is under way using the archived data from balloon-launched radiosondes. The data are often available at least once a day from a worldwide network of stations over a period of up to 50 years, and the height range covered available often extends from the surface up to 30 km or more, thus including the entire lower stratosphere.

In the tropics and subtropics data coverage is particularly good for several island stations in Micronesia and Hawaii, and the study has begun with a detailed investigation of temperature variations at these stations. Long-term cooling is often difficult to detect, partly because of the large seasonal variation and such additional factors as the stratospheric quasi-biennial oscillation (QBO), the ENSO cycle, and volcanic eruptions that saturate the tropical lower stratosphere with sulfuric-acid aerosol particles. However, the records do show a remarkable cooling that has taken place in the 1990s at the stations examined so far, producing some of the lowest temperatures of the entire record, and amounting to several degrees below the normal seasonally adjusted average. The cause of this cooling is still under investigation, but it seems to be too large and too rapid to be attributable to the radiative effects mentioned above. The possibility that it is related to the removal of volcanic aerosol by subsidence into the troposphere is under active study. As an example, the figure below shows monthly mean temperature anomalies (i.e., departures from the long-term seasonal average) at the 40 hPa pressure level (~22 km altitude) over the radiosonde station at Lihue, Hawaii (22.0° N). The cooling trends are shown by least-square straight-line fits to segments of the data.



Local Space and Time Scales of Tropical Deep Convection

Project Personnel: Prashant Sardeshmukh, Lucrezia Ricciardulli

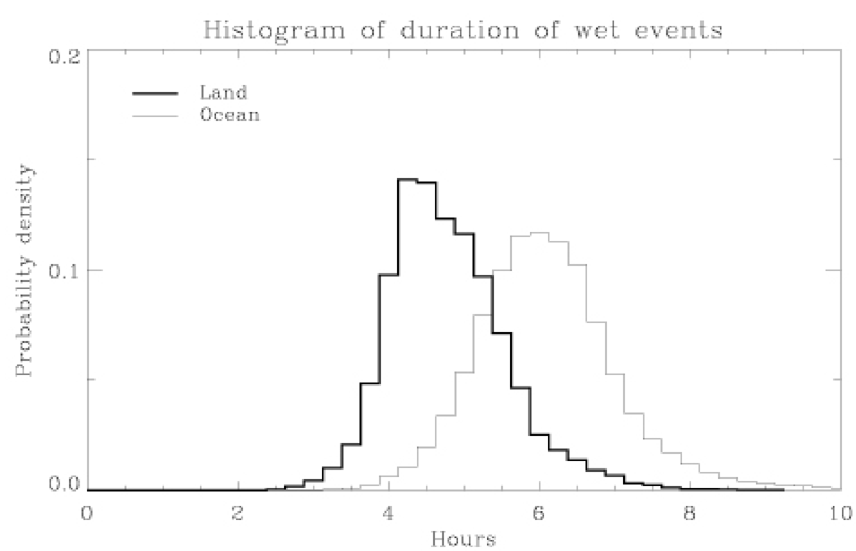
Theme(s): Climate System Variability

Payoff: Improved understanding of tropical convection

Funding Source: NOAA, CIRES

In a recently completed study, we estimated the space and time scales of tropical deep convection via analysis of three-hourly Global Cloud Imagery (GCI) data for three years at high spatial resolution. Our emphasis was on estimating the *local* space and time scales rather than traditional zonal wavenumber-frequency spectra. This was accomplished through estimation of local spatial lag-autocorrelations, the conditional probability of convection at neighboring points, and the expected duration of convective events. The spatial autocorrelation scale was found to be approximately 130 km, and the mean duration of convective events approximately 5.5 hours, in the convectively active areas of the tropics. There is a tendency for the spatial autocorrelation scales to be shorter over the continents than oceans (95-155 km *vs.* 110-170 km). The expected duration of convective events likewise tends to be shorter (4-6 hours *vs.* 5-7 hours). In the far western Pacific, these differences are sharp enough to legitimize the notion of the Indonesian archipelago as an extended maritime continent with a distinctive shape. Consistent with many other studies, the diurnal variation of the convection was also found to be strikingly different over the continents and oceans. The diurnal amplitude over land is comparable to the long-term mean, raising the possibility of significant aliasing across time scales. Our simple analysis should be useful in evaluating and perhaps even improving the representation of convective processes in general circulation models.

To illustrate, the probability distribution of the duration of deep convective events (characterized as "wet" events in our study given the close association between deep convective activity and rainfall) is shown separately for tropical land and ocean areas in Figure 4. The mean (plus and minus 1 standard deviation) of the land and oceanic values are 4.9 ($\pm$ 0.8) and 6.2 ($\pm$ 0.9) hours, respectively. Although the overlap between the distributions is considerable, the general tendency for the durations to be shorter over land is clear.



Changes of Subseasonal Atmospheric Variability during ENSO Winters

Project Personnel: Prashant Sardeshmukh, Gil Compo, and Cécile Penland

Theme(s): Climate System Variability

Payoff: Improved understanding and prediction of ENSO impacts

Funding Source: NOAA

The effect of ENSO on subseasonal extratropical variability can be distinct from that on seasonal mean quantities, and can have important practical implications. For instance, El Nino may alter the occurrence of both cold waves and hot spells in a winter. The effect is a meaningful change in the risk of extreme weather, even though little seasonal mean signal might be evident. We have recently estimated the effects globally from large ensembles of GCM integrations for the El Nino winter of 1987 and the La Nina winter of 1989, and compared them with observational composites derived from 11 El Niño and 11 La Niña events in the recent record. The purpose of this comparison was to gauge the robustness of the changes of variability, their predictability, and their variation from event to event.

The main result from this analysis, shown in **Figure 2**, is that the patterns of the tropical SST-forced anomalous height variability are markedly different for the synoptic (2 to 6 days), intraseasonal (8 to 45 days), and monthly (30 -day average) time scales. **Figure 2** shows the anomalous variance difference of 500 mb heights on these time scales. The results for La Niña (not shown) are similar and generally of opposite sign. The comparison between the GCM and observational panels is not clean. Nevertheless, their gross similarity is reassuring, both for the robustness of the changes of variability and this GCM's ability to simulate them. The main effect on the synoptic scale is a southward shift of the storm track over the Pacific ocean and North America. On the intraseasonal scale, it is a decrease of height variance over the north Pacific, consistent with a tendency of reduced blocking activity during El Niño. On monthly (and seasonal) scales there is a suggestion of an overall increase of variance. These differing ENSO impacts on extratropical variability on different time scales have very different implications for the risks of extreme anomalies on those scales. We believe that three quite distinct dynamical mechanisms are responsible for such sharp differences, and are currently investigating them in a hierarchy of dynamical models.

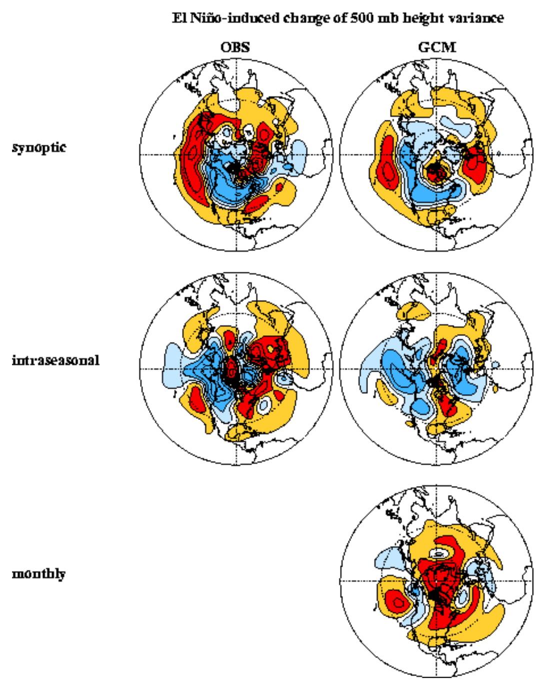


Figure 2. El Niño-induced changes of variance on three different subseasonal time scales. The quantity plotted is the square root of the anomalous variance, with red shading for positive and blue for negative anomalous variance. The left panels are based on statistics during 11 observed 11 El Niño and 11 observed "neutral" JFM winters in the NCEP reanalysis dataset. The right panels are derived from a large AGCM ensemble with observed SST forcing for the El Niño winter of JFM 1987. Top panels: Synoptic scale (2 to 6 day periods), Middle panels: Intraseasonal scale (8 to 45 day periods). Bottom panel: Monthly scale (30-day averages). Contours are drawn at 8 m intervals starting at 4 m in the top panels, and at 16 m intervals starting at 8 m in the middle and lower panels.

Understanding the Semiannual Variation of Atmospheric Angular Momentum

Project Personnel: Prashant Sardeshmukh, Huei-Ping Huang

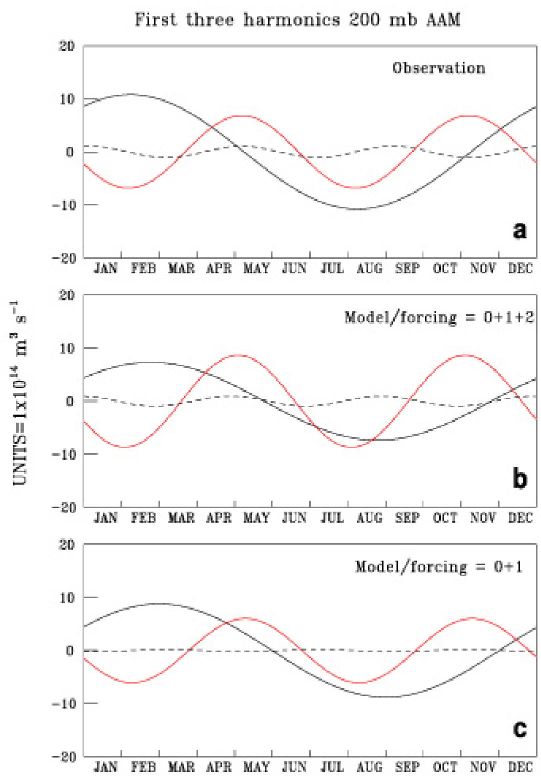
Theme(s): Climate System Variability

Payoff: Improved understanding of semiannual variations in the climate system

Funding Source: NOAA

The annual variation of global atmospheric angular momentum (AAM) is dominated by its first and second harmonic components. The first harmonic is associated with maximum global AAM in winter (December-January-February) and minimum in summer, but the second harmonic is important enough to produce a distinct secondary midwinter minimum. Locally, the second harmonic has largest amplitude in the tropics and subtropics of the upper troposphere. At present little is known concerning the fundamental cause of this semiannual variation.

In a recently published study, we investigated the problem by focusing on the upper-tropospheric winds, whose angular momentum is an excellent proxy of global AAM. The annual variation of the rotational part of these winds (the part that contributes to the global AAM) was diagnosed in a nonlinear upper-tropospheric vorticity-equation model with specified horizontal wind divergence and transient-eddy forcing. The divergence forcing is the more important of the two, especially in the tropics and subtropics, where it is associated with tropical heating and cooling. Given the harmonics of the forcing, our model predicted the harmonics of the response, that is, the vorticity, from which the harmonics of angular momentum could then be calculated. The surprising but clear conclusion from this diagnosis was that the second harmonic of AAM arises more as a nonlinear response to the first harmonic of the divergence forcing than as a linear response to the second harmonic of the divergence forcing. This is nicely illustrated in **Figure 3**, which shows the first three harmonics of the AAM as observed (top panel), as simulated by our model by specifying the annual mean and first two harmonics of divergence forcing (middle panel), and by specifying the annual mean and only the first harmonic of divergence forcing (bottom panel). This result has important implications for general circulation model simulations of semiannual variations, not only of global AAM but also of other quantities.



Huang and Sardeshmukh (2000)

Modeling and Prediction of Weekly Circulation Anomalies

Project Personnel: Prashant Sardeshmukh, Matthew Newman, Chris Winkler

Theme(s): Climate System Variability, Advanced Observing and Modeling Systems

Payoff: Extending atmospheric predictions beyond Week 2

Funding Source: NOAA, ONR

We have recently constructed a linear inverse model (LIM) suitable for studies of atmospheric variability and predictability on weekly time scales using global observations of the past 30 years. Notably, it includes tropical diabatic heating as an evolving model variable rather than as an externally specified forcing. It also includes, in effect, the feedback of the extratropical weather systems on the more slowly varying circulation. We have found both of these features to be important contributors to the model's realism.

The model is concerned with the behavior and prediction of 7-day running mean anomalies of the extratropical streamfunction and column-averaged tropical diabatic heating. It is better at forecasting Week 2 anomalies than a dynamical model based on the linearized equations of motion (with many more than the LIM's 37 degrees of freedom) that is forced with *observed* tropical heating during the forecast. Indeed at Week 2 the LIM's skill is competitive with that of NCEP's medium range forecast (MRF) model with nominally $O(10^6)$ degrees of freedom. At Week 3 it is demonstrably better. The upper panel of **Figure 1** shows a comparison of Week 3 forecast skill during the four winters of 1985/86 - 1988/89.

The LIM formalism also allows one to estimate predictability limits in a straightforward manner. Given that in many cases the predictable signal is associated with tropical forcing, one can quantify the effect of that forcing on extratropical predictability. Our conclusion is that without tropical forcing, extratropical weekly averages may be predictable only about two weeks ahead, but with tropical forcing properly represented; they may be predictable as far as seven weeks ahead. This difference is highlighted in the lower panel of **Figure 1**. This suggests that accurate prediction of tropical diabatic heating, rather than of tropical sea surface temperatures *per se*, is key to enhancing extratropical predictability on these time scales.

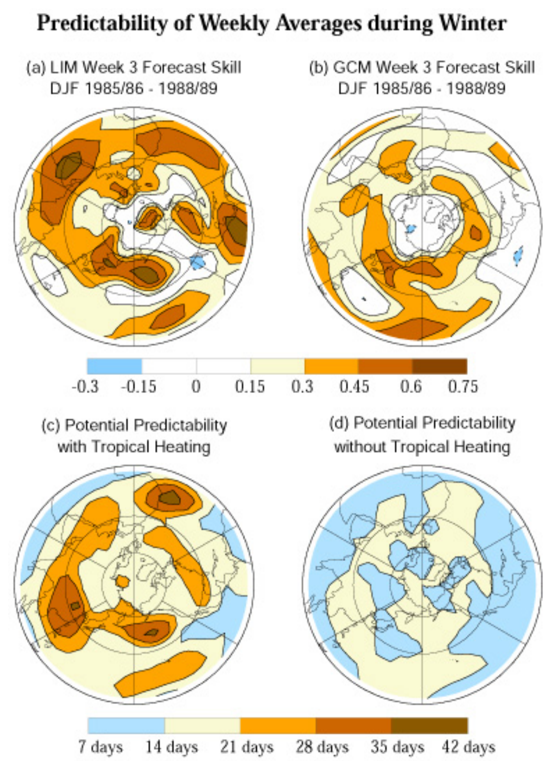


Figure 1: Forecast skill and predictability of weekly averages during winter. Top: Correlation of observed and Week 3 forecasts of upper tropospheric streamfunction anomalies averaged over 52 forecast cases in the winters of 1985/86 - 1988/89. Bottom: Potential predictability limit: forecast lead at which skill (i.e., the correlation of observed and predicted anomalies) drops below 0.5. (a) Determined from the full LIM. (b) Determined from a version of the LIM in which the effects of tropical forcing are removed.

Earlier Spring Snowmelt in Northern Alaska as an Indicator of Climate Change

Project Personnel: R.S. Stone, E.G. Dutton, J.M. Harris, D. Longenecker

Theme(s): Climate System Variability; Regional Processes

Payoff: Better understanding of the physical processes that influence Arctic Climate

Funding Source: International Arctic Research Center (IARC) - University of Alaska

Regional climate models fail to adequately simulate the complicated feedbacks that are peculiar to the Arctic. Empirical analyses of data from Barrow, Alaska and other North Slope sites provide a better physical understanding of climate change in this region. In particular, data from the NOAA/CMDL Barrow Observatory (BRW) reveal some primary factors that determine the annual cycle of snow cover there. The timing of the spring melt influences the surface radiation budget (SRB) and temperature regime of northern Alaska. Results define a baseline for evaluating future climate change in this sensitive region of the Arctic, and can be used to verify model simulations and validate remote sensing algorithms.

A trend towards an earlier disappearance of snow in spring (melt date) in northern Alaska is documented (**Figure 1**). Earlier snowmelt is, in part, the consequence of decreased snowfall in winter, followed by warmer, cloudier spring conditions (**Figure 2**). These changes are, in turn, attributed to shifts in synoptic circulation patterns. The resulting perturbation in the SRB has very likely contributed to the springtime warming trend observed in this region since the mid 1960s through a process referred to as the temperature-albedo feedback.

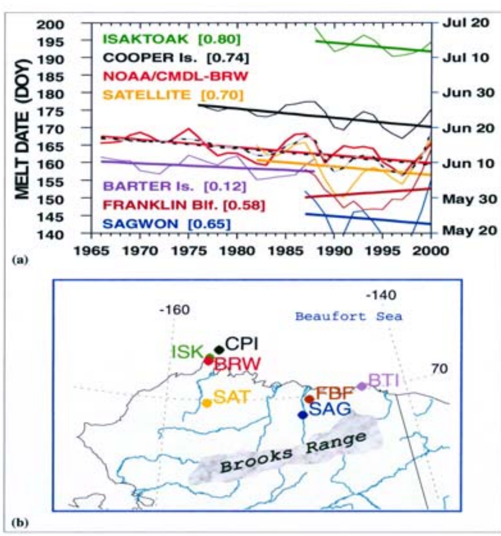


Figure 1. *(a) Analyses of six independent time series of measured or proxy melt dates that are compared with the 1966-2000 NOAA/CMDL-BRW record (red). 5-year smoothed time series and linear fits are shown. Each is correlated with the BRW record with coefficients indicated [in brackets] for individual sites that are labeled and color-coded. The dashed analysis (unlabeled) is for an ensemble average of the 142-station years, normalized to the BRW timeframe. (b) Map of Alaska's North Slope showing the location of sites making up the ensemble.*

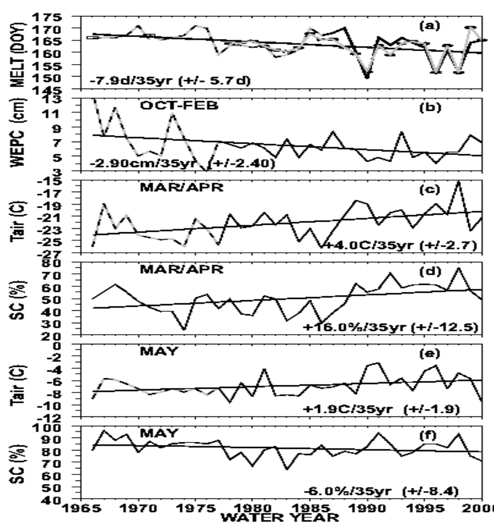


Figure 2. *1966-2000 time series of (a) observed and modeled (filled ellipses) melt dates at BRW, (b) October-February snowfall expressed as water-equivalent precipitation (WEPC), (c) average March/April air temperatures, d) average March/April total sky cover, (e) average May air temperatures, and (f) May total sky cover. Bottom legends give results of linear fits with uncertainties (given in parentheses) at the 95% level of confidence. Water year includes the previous autumn season when considering the October -February period.*

Variability of Freezing Levels and Melting Season Indicators in Selected High-Elevation Regions Around the Globe in the Last 50 Years

Project Personnel: Henry F. Diaz and Jon K. Eischeid

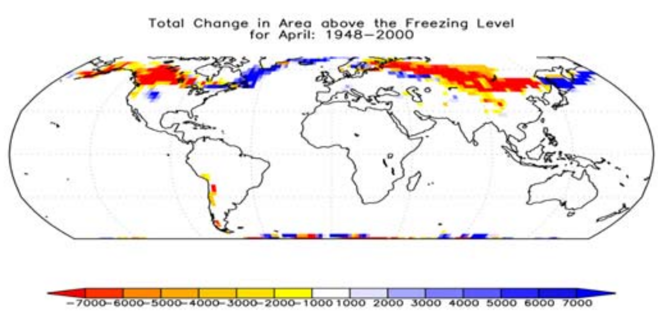
Theme(s): Climate System Variability

Payoff: Verification and diagnostics of global climate model projections in support of IPCC and National Assessment activities.

Funding Sources: U.S. Dept. of Energy, NOAA.

The elevation above sea level at which the mean air temperature is around 0˚C is an important parameter, because it denotes the approximate position of permanent ice and snow on the surface. Due to feedback effects from the snow/ice albedo and requirements for latent heat energy to change water from its solid to its other phases, this variable—the height of freezing level surface or FLS—constitutes an important indicator of climate variability and change. An analysis of the pattern of change in freezing level height (FLH) for major mountain areas of the globe has been carried out, based on a 50-year record of free atmospheric temperatures from the NCEP/NCAR Reanalysis data set. In addition, we have computed an index of melting degree-days (MDD) for these same regions, where the number of degrees per day at the surface topography in the model that exceed the threshold of 0˚C are accumulated on a monthly basis. A second version of the MDD data was computed based on the mean elevation of the surface as derived from a 5-min resolution DEM.

We find that FLH are strongly controlled by tropical Pacific SSTs, particularly in the American Cordillera. For the period 1948–2000, tropical FLH went up by about 73 m (53 m for the period 1958–2000). The recent 3-year episode of cool (La Niña) ocean temperatures in the Pacific has depressed FLH in most of the tropics (and particularly in the Americas). In terms of melting degree-days, the net change from 1948–1998 amounts to about a 3.1% increase in annual mean values for the Cordillera region (for the period 1958–1998, the corresponding change is about half as large). We have also calculated the monthly change in the surface area of the continents located above the local mean value of the 0˚C isotherm. The figure below illustrates the 50-year changes in surface area above the FLS for the month of April when the largest globally-integrated changes are observed.



Map showing net changes in surface area above the FLS for the month of April.

Closure of the Indonesian Seaway, Aridification of East Africa, and the Ice Age

Project Personnel: Mark A. Cane (Columbia University), Peter Molnar

Theme(s): Climate System Variability; Geodynamics

Payoff: Clue to how subtle changes in the distribution of continents and oceans can dramatically affect climate.

Funding Source: NSF (to Cane), CIRES (to Molnar)

We suggest that the closing of the Indonesia Seaway in the last 3-5 million years triggered the aridification of East Africa (when and where humans evolved), and may have provided the switch that initiated the cooling leading to the ice ages. Since 3-5 million years ago, climate in East Africa changed from moist to arid and cooling at high northern latitudes led to the growth of ice sheets there. Simultaneously, the northern edge of New Guinea, which lies almost exactly at the equator at present, moved northward at 70 km/Myr (or ~3˚ since 5 million years ago). Moreover, much the island of Halmahera, which lies NW of New Guinea and obstructs flow of water from the equatorial Pacific into the Indian Ocean, emerged in the last 3-5 million years. These correlations suggest the possibility of causal connections among tectonics and climate.

At present, relatively cool water from the North Pacific passes into the Indian Ocean as the Indonesian Throughflow. Yet, the temperature of water below the surface and above the thermocline (to depths of ~150 meters) in the North Pacific is 5-7˚C warmer than that south of the equator at the same depths. Presumably, when New Guinea lay farther south and Halmahera was more submerged, warm water from the South Pacific flowed into the Indian Ocean. Simple analytic calculations, corroborated by ocean GCM runs, show how the source of Indonesian Throughflow depends on the position of a boundary such as that formed now by New Guinea and Halmahera: if its northern edge lies in the northern Hemisphere, as it does today, the North Pacific supplies the vast majority of the throughflow; conversely, a Halmahera-New Guinea boundary stopping in the southern hemisphere, and not crossing the equator, allows water from the South Pacific to form the majority of the Throughflow. Thus, 3-5 Million years ago, Indonesian Throughflow consisting of warm Pacific water from south of the equator should have made the Indian Ocean warmer (by 2-3˚C), which would have caused a more humid East Africa; blockage of that warm water since 3-4 Myr ago led to the aridification of that region.

Perhaps more important, by blocking the westward flow of warm Pacific water, northward movement of New Guinea and the emergence of Halmahera, may have created the warm pool, necessary for ENSO. Before New Guinea blocked that warm water, the tropical Pacific would have been more zonally symmetric than it is today, which paleoceanographic data corroborate, with no warm pool in the western Pacific. Efficient heat transport to high latitudes, characteristic of El Niño and its teleconnections, would have prevented the formation of ice sheets in Canada. Thus, by blocking the warm water above the thermocline south of the equator, New Guinea's northward movement would have switched a stable El Niño state to the more variable ENSO conditions, with weaker meridional heat transport to the extratropics.

If this series of arguments is correct, it reminds us that the transport of heat from the tropics to the poles may control, as much as anything, the warming of the high latitudes, for it is in the high latitudes where changes in temperature have been greatest and presumably will be. Conversely, the key to understanding paleoclimate lies in treating differences between past and present as minor differences from the present-day basic state, as reflected in teleconnections.

Inaugural Survey of Russian and Chinese Emissions of Ozone-Depleting Substances from In Situ Measurements aboard the Trans-Siberian Railway

Project Personnel: D.F. Hurst, P.A. Romashkin, J.W. Elkins

Theme: Climate System Variability

Payoff: Improved knowledge of the abundance of ozone-depleting substances (ODS) in southern Siberian air masses. At a minimum, results from this study provide a firm basis for continued monitoring of ODS in Russia, and might permit similar inaugural measurements in other nations where under-reporting and/or illicit production and consumption of ODS is possible.

Funding Sources: CIRES, NASA, NOAA

Anthropogenic emissions of chlorinated and brominated source gases have dramatically increased the burdens of ozone-depleting chlorine and bromine in the stratosphere during the last five decades. This build-up of stratospheric halogens has resulted in a detectable decline of global ozone abundance and severe wintertime losses of ozone over Polar Regions.

The Montreal Protocol and its amendments provide international regulations to greatly reduce global emissions of the principal ozone-depleting substances (ODS) by curtailing their production and consumption over a 26-year period that began in 1989. Here, principal ODS include chlorofluorocarbons (CFC), chlorinated solvents CH_3CCl_3 (methyl chloroform) and CCl_4 (carbon tetrachloride), and halons (bromochlorofluorocarbons and bromofluorocarbons. Production and consumption of these ODS should now be completely eliminated in developed countries, while developing countries should be preparing to meet upcoming cap and reduction targets.

Global compliance with the Montreal Protocol can only be assessed by long-term global monitoring of ODS in the atmosphere and comparison of measured abundance trends with modeled trends based on reported emissions. Modeled and measured trends agree, with two notable exceptions, CFC-12 (a refrigerant) and halon-1211 (a fire extinguishant), which continue to accumulate in the atmosphere at rates greater than predicted from reported emissions. The discrepant trends raise two questions about ODS production and consumption: (1) Which nation(s) is (are) under-reporting and (2) are the emissions from illicit activities? Investigation requires regional-scale measurements that are akin to a "fishing expedition" for ODS emissions.

During June 27 – July 10, 2001, over 11,000 in situ measurements of CFC-12 and halon-1211, and 5000 measurements of CFC-11, CFC-113, $CHCl_3$, CH_3CCl_3, CCl_4, and four other trace gases were made along 17,000 km of the trans-Siberian railway between Moscow and Khabarovsk, Russia. The measurements were part of the seventh Trans-Siberian Observations in the Chemistry of the Atmosphere (TROICA-7) scientific expedition as a collaboration between U.S., Russian, and German scientists. Elevated levels of CFC-12 and halon-1211 were frequently observed along the route, typically near the larger cities of Siberia. Work is ongoing to evaluate the sources of these spikes to ensure they are not contamination from the train itself. Correlations with other tracers of anthropogenic pollution, CO, NOx, and O_3, are being investigated to help identify possible types of sources of these two important ODS.

Stratospheric H_2O: A New Player in Stratospheric Cooling and Ozone Depletion

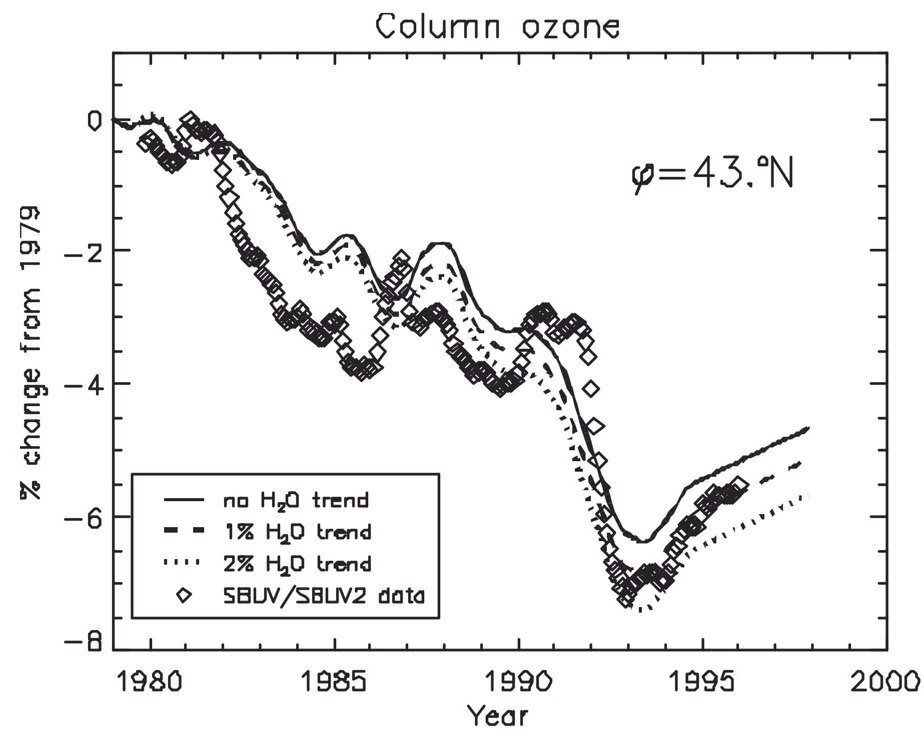
Project Personnel: V. Dvortsov, S. Solomon

Theme(s): Climate System Variability

Payoff: Improved understanding of stratospheric ozone depletion.

Funding Source: NOAA

It has long been known that carbon dioxide and other greenhouse gases play a major role in cooling the stratosphere, and that ozone depletion also contributes. Recent work by others has called attention to the role of water vapor in stratospheric cooling, and our group has added to this key issue with a comprehensive study examining the effects of observed trends of stratospheric water vapor for both ozone depletion and temperature changes. We have shown that water vapor trends have likely made significant contributions to the decline in mid-latitude ozone observed over the past twenty years, and that it played a substantial role in the stratospheric cooling observed. This work helps to quantify the role of a new player in the stratospheric game, thus advancing understanding of the factors contributing to the trends observed (Dvortsov and Solomon, J. *Geophys. Res*., 2001).



Role of Water Clusters in Radiative Transfer

Project Personnel: V. Vaida, J.S.Daniel, H.G. Kjaergaard, L.M.Goss, A. F.Tuck

Theme: Climate System Variability

Payoff: Provide a mechanism with predictive power for diffuse absorbers of solar radiation.

Water molecules bind easily to one another and to molecules and radicals found in the atmosphere, to form complexes with properties intermediate between the single molecule vapor and the liquid state. The weak interactions responsible for complexation modify the low energy (infrared and near IR) ro-vibronic states as well as the high energy (ultraviolet) electronic states of individual molecules providing new opportunities for absorption of solar and terrestrial radiation and for light initiated chemical reactions in the atmosphere.

A combination of experimental and theoretical studies using tools and concepts of chemical physics in conjunction with atmospheric modeling led us to estimate the atmospheric role of water bimolecular complexes. Water molecules absorb solar and terrestrial radiation, contributing significantly to the greenhouse effect. Recent comparisons of field measurements and climate models show discrepancies that can only be reconciled if additional absorbers are included in atmospheric models. Our work has shown that in the near IR, binary complexes of water absorb an additional $3Wm^{-2}$ over known absorption of individual molecules, accounting for some of the above-mentioned discrepancies between atmospheric measurements and models. Extrapolation of our results to a global worming scenario with increased temperatures shows that the importance of water complexes increases nonlinearly to provide an amplifier for the anthropogenic temperature increase.

State of the Cryosphere Web Stie (nsidc.org/NASA/SOTC)

Project Personnel: Richard Armstrong, Mary Jo Brodzik, Mark Dyurgerov (INSTAAR), Jim Maslanik, Mark Serreze, Julienne Stroeve, Tingjun Zhang

Theme(s): Climate System Variability

Payoff: Provides a current and concise overview of the status of snow and ice as indicators of climate change

Funding Source: NASA

Global mean temperatures have risen over the past 100 years by about 0.6 C. Over half of this increase has occurred in the last 25 years. There is variability in temperatures from year to year, and also from decade to decade superimposed on the longer upward trend. The range of natural variability in global temperature appears to be about plus or minus 0.2 C, so that it is only after the late 1970s that global mean temperatures emerge from the noise of natural variability. In some regions, extreme warming has been detected. Locations in Alaska and northern Eurasia, for example, have warmed by nearly 6.0 C in the winter months over the past 30 years.

At the "State of the Cryosphere" web site we investigate the response of snow cover, glaciers, sea ice, and the related parameter sea level to this recent global warming. Various forms of satellite remote sensing allow the monitoring of snow and ice surfaces at varying spatial scales over the most recent 20 to 30 years. In all cases in the Northern Hemisphere, regardless of parameter or measurement method, the amount of snow and ice has been decreasing over the past several decades. For example Figure 1 presents trends in snow cover extent for the Northern Hemisphere derived from two different satellite sensors (visible and passive microwave). Both data sources indicate that the total snow cover extent has been decreasing by about 2 percent per decade. Figure 2 provides a similar time series for Northern Hemisphere sea ice extent derived from passive microwave data. These results indicate a decrease in area of about 3 percent per decade. In contrast, the Antarctic sea ice extent appears to have increased in area by slightly more than 1 percent over the same period. At our web site we also introduce the topic of permafrost. However, because reliable data on hemispheric-scale permafrost extent have only recently become available, examples presented provide only a snapshot of current permafrost conditions rather than time series data. Future additions to this web site will include data on the behavior of ice sheets and ice shelves.

Figure 1: Northern Hemisphere Snow Extent Anomalies

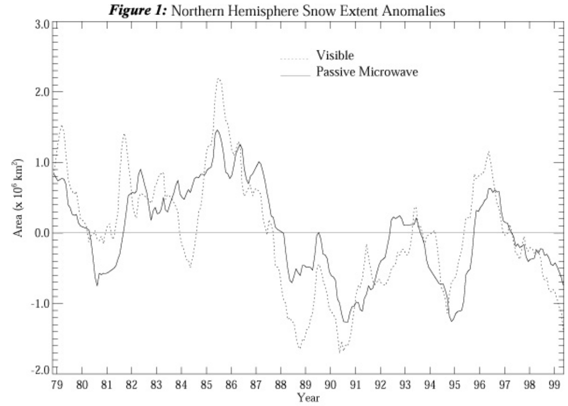
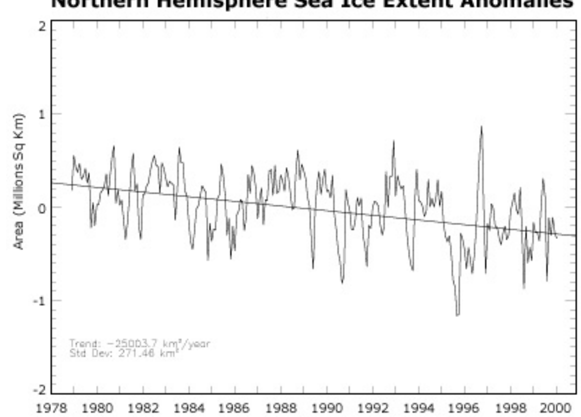


Figure 2:
Northern Hemisphere Sea Ice Extent Anomalies



The Development of a Climate Time Line Information Tool

Project Personnel: Dan Kowal

Theme(s): Climate System Variability

Payoff: Simplifying access to climatological data through a user-friendly, web-based format; educational outreach to the public

Funding Source: CIRES

The "Climate Time Line" or CTL tool currently in development at the National Geophysical Data Center will provide a climatic and "place-based" context for current weather patterns and a pre-instrumental context for current climate trends. Two audiences-GLOBE students and water managers involved with the Western Water Assessment—are targeted in the pilot project phase to test the CTL as a learning and decision-making support tool. Weather, climate and paleoclimatic observations will be integrated through a web-based interface that can be used for comparing data collected over 10 year, 100 year and 1000+ year periods, and made accessible and meaningful to non-technical users. This project is funded by an Innovative Research Award given by CIRES. Mark McCaffery and Dan Kowal are the principal investigators from NGDC.

The Climate Time Line prototype will include the following features: 1) Access to diverse data sets such as NCDC's Historic Climate Network, GLOBE Student Data Archive, World Data Center for Paleoclimatology and historical streamflow data from the USGS; 2) Map Locator/Search Utility for regional inquiries and comparison views; 3) Varying temporal and spatial displays; 4) Tutorial and help sections to guide and support users; 5) Supporting materials including a "Powers of Ten" primer examining variability at various timescales; and 6) Statistical assessment tools.

The CTL prototype offers a novel approach in the scientific analysis of climate and hydrology data. It will facilitate inquiries by simplifying access to environmental data. Additionally, it will provide historical timelines for the intended user to compare the development of human cultures in relation to climate trends and variability—promoting an inquiry-rich learning environment.

Throughout the pilot project phase, the CTL will undergo evaluation particularly in the area of usability, followed by a pre- and post-assessment of its educational impact on the targeted, non-technical audience. The progress of this project can be viewed at: http://HyperNews.ngdc.noaa.gov/HyperNews/get/ClimateTimelineProject.html.

Research Theme: *Regional Processes*

Many of our research endeavors have a regional focus because they address a particular confluence of geography, demographics, weather and climatic regimes. These constituents include human populations ranging from those coastal megalopolises to those of the indigenous people on the margin of the Arctic Ocean, all of who must coexist with sensitive aquatic and terrestrial ecosystems in a highly variable and evolving climate. Indeed, the impact of short-term climate variability and extremes is often regionally focused, influencing very specific populations, economies, and ecosystems. Specific areas of effort include:

Region-Specific Impacts of Climate Variability and Extreme Events

The impact of climate variability is regionally specific, often focused within natural boundaries associated with topography, watersheds, and/or other geographical. The goal here is to couple enhanced observations and research within regions characterized by a strong climate variability signal with analysis of past data and improved modeling. A special emphasis will be on determining factors influencing the occurrence of extreme events.

Atmospheric Chemical Forecasting

Improved forecasts of the chemical composition of the atmosphere are relevant to public health and safety issues. This topic undertakes research that contributes to the development of air quality prediction and forecasting capabilities. This research will seek to identify the natural and anthropogenic emissions that influence the formation of ozone and fine particles in urban, rural regions and coastal areas of the United States and determine the chemical and meteorological processes that control their transformation and redistribution. The research under this topic will underlie national, regional, and local efforts to evaluate and improve air quality.

Regional Air Quality

The goal of this topic is to improve the understanding of the chemical and meteorological features that determines air-quality in various regions of the United States.

Intercontinental Transport and Chemical Transformation

The aim of this research is to elucidate the processes that determine the intercontinental transport of photochemical pollution and control the chemical transformation that occurs during this transport.

Surface/Atmosphere Exchange

This goal is to improve the understanding of the role that surface-atmosphere exchange plays in shaping regional climate and air-quality. Accurately characterizing the exchange of heat, momentum, moisture, gases, and aerosols at the surface of the Earth provides one of the major challenges for the diagnoses and prediction at regional scales. Oceans cover some 70% of the globe and maintain much of the memory of past climate that is carried into the future. They constitute one of the major data voids of the Earth yet are the major supplier of moisture that eventually flows through terrestrial and aquatic ecosystems back to the ocean.

Hydrological Cycles in Weather and Climate

This objective is to better observe, model, and predict the consequences of climate change and variability on hydrological variables on time scales ranging from those of flash floods to those of the Pacific Decadal Oscillation and on multiple spatial scales.

High Latitude Regional Processes

This goal is to carry out interdisciplinary studies of high latitude regions of the Earth where atmosphere, water, ice, and land meet and are expected to allow complex responses and feedbacks to climate variability and change on local scales.

NOAA-CIRES Western Water Assessment

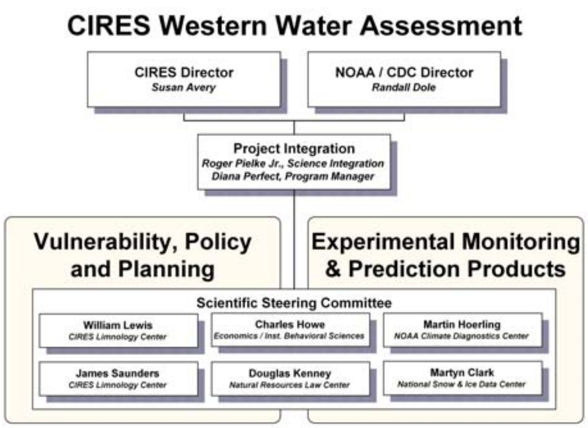
Project Personnel: Over 30 researchers and faculty from CIRES, NOAA, various University of Colorado Departments, and Hydrosphere, Inc.

Theme(s): Regional Processes

Payoff: Assessment of sensitivity to climate variability and the development of climate-related information and products to assist decision makers in the region

Funding Source: NOAA-OGP

The Western Water Assessment (WWA) team has made significant progress during the past year in developing its approach to truly integrated research. We list "learning," the "process of learning," and our team's enthusiasm for it as an emergent accomplishment and foundation for success in our integrated research. This evolution was the result of frequent group and sub-group meetings to develop a shared language and common methodology. We continued to develop technical tools for integration and expanded our web site for information sharing. We held a GIS workshop for team members in September 2000, and leveraging a grant from the FGDC (Federal Geographic Data Committee), we developed some GIS web capabilities. The coordinated presentation of two talks and seven posters at the 12th Symposium on Global Change and Climate Variations of the American Meteorological Society meeting in Albuquerque was another group accomplishment.



The management structure of the WWA has evolved over the last four years to its current structure shown in the accompanying figure. The two project goals are reflected in this diagram as themes of the project: 1) vulnerability, policy, and planning, and 2) experimental monitoring and prediction products. Our management structure is adaptive and it will continue to evolve to meet the needs of the project.

Our pilot phase studies have been focused on the South Platte Basin with some additional work on the Upper Colorado River Basin. We have completed an analysis of the South Platte River, which demonstrates the effects of climate variation water quality and now plan to brief state and federal regulatory agencies on our findings and work with them to incorporate climate variability in their permitting processes.

A major success of the past year has been integration of physical science with user studies. One outcome of these interactions is our new focus on "demand driven" research. A vigorous research program was spurred on by our increased awareness and understanding of societally relevant problems in the Interior West. Our entire process is focused on contributing to an enhanced decision process. We recognize that decisions are made in a multi-stress context that not only includes climate but also social trends, institutional structures, public values, and politics. In a major step toward integration, we have developed a modeling approach to assess the sensitivity of the region to climate variability, the feasibility of various forms of adaptation, and the residual vulnerability. We have planned this methodology to ultimately provide a synthesis of vulnerabilities throughout the entire Interior West region.

The Importance of Water Markets in the Reallocation of Water in the South Platte Basin

Project Personnel: C. Howe and C. Goemans

Theme: Regional Processes

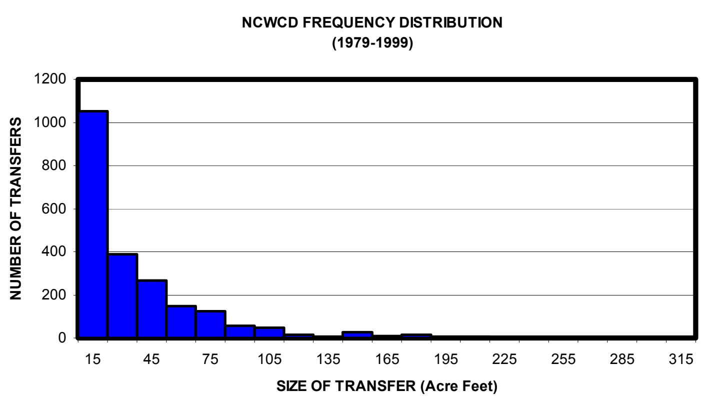
Funding Sources: NOAA-OGP and the General Service Foundation.

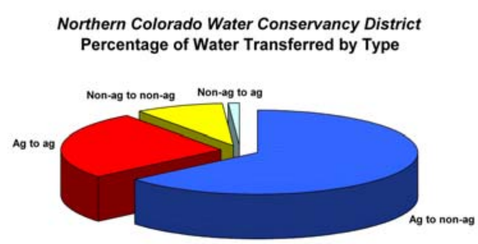
The legal system relating to water in the western United States is an "appropriations" or "priority" system that treats the use of water as personal property subject to transfer or sale. In the western U.S., the development of new water supplies has become extremely expensive both in economic and environmental terms. Also, roughly 85% of the consumptive use of water still takes place in irrigated agriculture, much in the production of low-valued crops. Thus it is important that water can be transferred from older, lower-valued uses to newer, higher-valued uses.

Water changes ownership or is leased through informal water markets. These transactions involve either the sale or lease of native water rights or shares in water distribution organizations (whose water availability is underlain by water rights). Most transfers are subject to review by the water court of each water administration division (corresponding to the major river basins) to assure that there is no injury to other water users.

To further our understanding of the working of water markets with the objective of increasing their effectiveness, all water right transfers in the South Platte Basin (Water Division 1) for the period 1979 through 1995 were identified and classified by size (acre-feet) and nature of buyer and seller. In addition, transfers of the shares in the Northern Colorado Water Conservancy District were analyzed because of the importance of the District (it provides about 30% of S. Platt supplies through imports). District shares don't have to go through water court, so a very active water market has developed within the District. Some characteristics of the Division 1 water rights transfers and transfers of the shares of the Northern District are shown below. The differences have important implications for the design of water markets.

An on-going activity that is drawing the social science components of the Western Water Assessment closer to the climatology components is the analysis of the ways in which climate variations affect the water market, i.e. the volume of water transfers and their prices.





Relationships between Water Quality and Climate Variability in the Interior West

Project Personnel: William M. Lewis, Jr., James F. Saunders, III, and Sujay Kaushal

Theme(s): Regional Processes

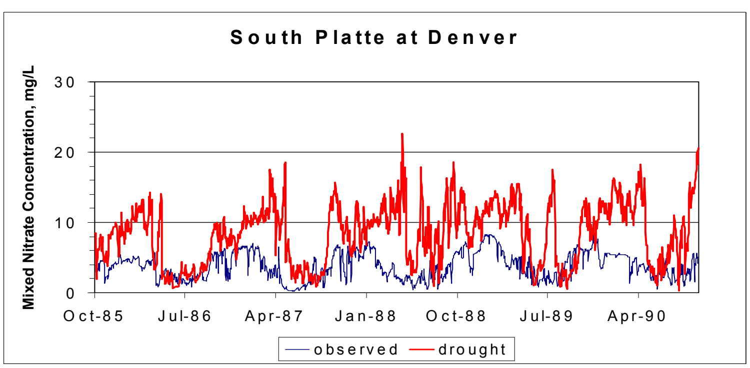
Payoff: A view of unsuspected vulnerability for water quality protection systems caused by multiyear periodicities in climate variables.

Funding Source: NOAA-OGP

The water quality protection system in the United States relies on accurate estimates of flow for surface waters that receive permitted discharges of waste. In determining the amounts of regulated substances to be discharged, the states, under direction from the USEPA, estimate the dilution that will be available under critical low-flow conditions, which are specified on the basis of probability of recurrence and duration for extreme conditions. In practice, critical low-flow conditions for the hundreds or even thousands of permitted discharges in any given state must be evaluated on the basis of short records for stream flow (e.g., 5 yr). The use of short records introduces bias through omission of climatic events that have recurrence intervals of multiple years (e.g., ENSO). The problem of greatest concern is overestimation of critical low flows, which may lead to systematic and severe deviations of water quality from the expected norms.

The potential for systematic errors in estimating critical low flows was explored empirically for the South Platte drainage of Colorado. Intervals of varying length were drawn from the longest gage records (ca. 1000 yr) and were used with algorithms that are used in permitting. Repeated sampling from the historical record for any given length of record provided a statistical basis for evaluation of the relationship between length of record and degree of error in estimating the true long-term low flow.

The study showed that there is unsuspected vulnerability in the water quality protection system of the United States due to the presence of synoptic climate variations that have periodicities of several years; an example is shown in Figure 1. As the understanding of ENSO and other recurring climatic events that have multiyear intervals becomes better, these sources of variation should be factored into calculations of low flows for purposes of water quality protection.



Hypothetical maximum concentration of nitrate: (1) consistent with low flows estimated from data for 1985-90 (lower line), and (2) consistent with flow during the 5-year period of lowest consecutive flows observed in the historical record (upper line).

Ecological Significance of Dissolved Organic Nitrogen in Streams Draining Undisturbed Watersheds

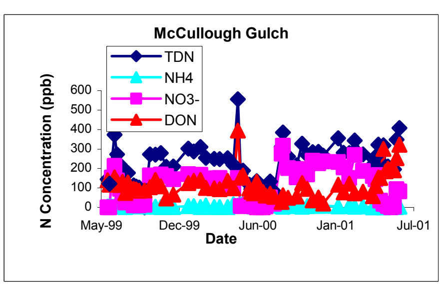
Project Personnel: S. S. Kaushal, W. M. Lewis, Jr.

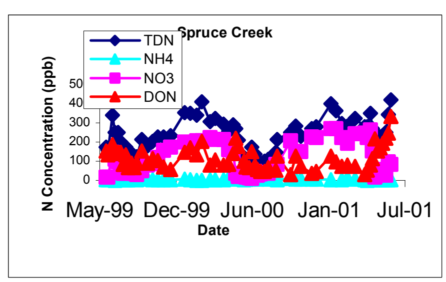
Theme(s): Regional Processes

Payoff: Assessment of the role of organic nitrogen as a source of nitrogen to aquatic food webs in streams receiving low levels of atmospheric nitrogen deposition

Funding Sources: NOAA-OGP

An understanding of baseline dynamics of nitrogen in undisturbed watersheds is crucial in predicting the effects of nitrogen deposition on aquatic systems in the future. Dissolved organic nitrogen comprises approximately 50% of the soluble fixed nitrogen exported from unaltered watersheds, yet little is known about its chemical composition, origins, and biological lability. Considerable effort has been devoted to understanding the dynamics of inorganic nitrogen (i.e. nitrate, nitrite, and ammonium) because these forms of nitrogen are currently regulated for the protection of drinking water and aquatic life. Organic nitrogen may also be biologically active, however, and its abundance and composition has important implications for water quality in rivers and lakes. Seasonal changes in the chemical composition and bioavailability of dissolved organic nitrogen were investigated in two second-order streams draining subalpine watersheds that receive low rates of N deposition (ca. 3 kg/ha/yr). Concentrations of dissolved organic nitrogen peaked sharply during early spring runoff (Figure 1) and were weakly related to discharge over a two-year period. Concentrations of nitrate declined to negligible concentrations during summer months (Figure 1) and were strongly influenced by biotic factors. A fractionation technique involving XAD-8 resins was used to characterize the composition of dissolved organic nitrogen. This technique allows isolation of humic substances (hydrophobic, refractory compounds originating from lignin) and non-humic substances (labile compounds such as amino acids, proteins, plant pigments etc.). During the study period, approximately 60-80% of dissolved organic nitrogen was of non-humic origin. The proportion of humic dissolved organic nitrogen increased during snowmelt because of changes in hydrologic flow paths through upper soil horizons. The relative carbon and nitrogen content of each fraction also changed at this time, but displayed contrasting patterns. The ratio of carbon to nitrogen in humic substances increased during snow melt to high values (characteristic of refractory plant materials). The C:N ratio of non-humic substances decreased to low values below 10 (characteristic of amino acids) suggesting a release of highly labile dissolved organic nitrogen from the watershed. Concentrations of non-humic dissolved organic nitrogen were strongly related to concentrations of nitrate suggesting the importance of biotic influence on production of this fraction of dissolved organic nitrogen. Bioavailability assays indicated that changes in the lability of dissolved organic nitrogen could be predicted from data on composition. Dissolved organic nitrogen is likely to be an important source of nitrogen to organisms in streams with low concentrations of inorganic nitrogen. It is likely that nitrogen deposition has increased the biological reactivity of organic nitrogen exported from watersheds due to subsequent increases in availability of inorganic nitrogen and mineralization in soils. This could have important implications for water quality further downstream in lakes, rivers, and estuaries.





Developing Hydrologic Prediction Capabilities in the Interior West

Project Personnel: Martyn Clark with Lauren Hay and George Leavesley of the USGS

Theme(s): Regional Processes

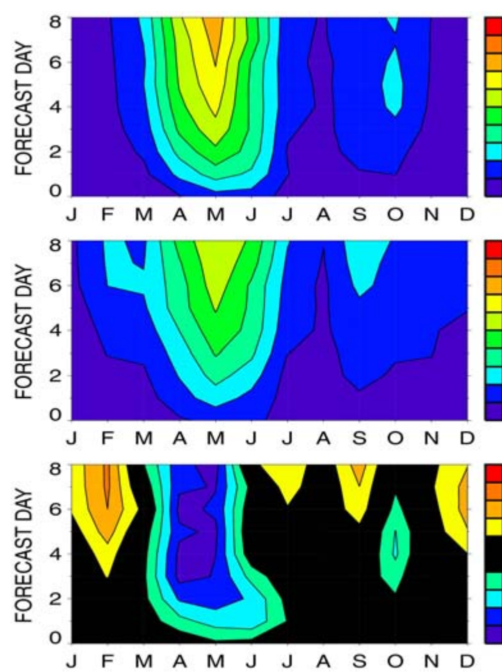
Payoff: Combining weather and hydrologic models to improve reservoir manager decision-making

Funding Sources: NOAA-OGP

Several applied research projects were initiated to address the information needs of reservoir managers in the Upper Colorado River basin. One was development of a system to predict streamflow on intraseasonal time scales using medium-range atmospheric forecast models as input to hydrologic models to provide short-term (1-2 week) forecasts of runoff. This involves a) downscaling the global-scale atmospheric forecast model output to provide estimates of precipitation and temperature at local scales in individual river basins; b) assimilate station and satellite precipitation and temperature observations to estimate basin initial conditions; c) using the forecasted precipitation and temperature as input to hydrologic models, run hydrologic models in ensemble mode to forecast runoff and estimate forecast uncertainty; and d) post-process hydrologic model output to remove systematic biases. We used the 8-day forecasts archived as part of the 40+ year NCEP/NCAR Reanalysis project to compare the performance of this system against the National Weather Services' operational streamflow forecasting techniques, the extended streamflow prediction (ESP) system, where the forecast ensemble used as input to hydrologic models is comprised of historical data of precipitation and temperature from all other years in the historical record.

In the figure, we demonstrate the performance of the two (ESP-and NCEP-based) forecasting techniques for the Animas River Basin, a small mountain snowmelt dominated watershed in southwestern Colorado. The contour plots show the month along the x-axis, the forecast day along the y-axis, and the Root Mean Square Error (RMSE) or the forecast improvement as the contoured variable. The top panel shows the climatology forecast error, computed using the difference between the observed flow and climatology forecasts. The middle panel shows the forecast error using the NCEP forecasts in place of the climatology. The bottom panel is the predominately influenced by rainfall.

difference between the top and middle panels. The most notable feature is the significant improvement of the NCEP-based runoff forecasts over runoff forecasts based on climatology, most apparent during spring when runoff in the Animas basin is highest and most variable. Improvements in forecast accuracy are derived from reliable springtime forecasts of maximum temperature that translates into credible estimates of snowmelt and runoff. The accuracy of the NCEP precipitation forecasts over the Animas basin was poor. Useful forecasts using NCEP output most likely occur because the Animas River basin is dominated by snowmelt (which is influenced by variations in temperature), and may not hold in other river basins where the surface hydrology is



River forecast error using climatology (top), NCEP forecasts (middle), and the difference (bottom)

Inuit Knowledge of Climate and Climate Change in the Eastern Canadian Arctic

Project Personnel: S. Fox, R. G. Barry

Theme(s): Regional Processes

Payoffs: (a) A more complete understanding of Arctic climate change and impacts through the integration of Inuit and scientific methods of observing and understanding the environment and (b) the development of frameworks and tools to help 'bridge the gap' between indigenous and scientific knowledge.

Funding Sources: NSF, SSHRC (Social Sciences and Humanities Research Council of Canada), CIRES

Arctic regions are already beginning to experience the impacts of climate change, such as permafrost degradation and thinning sea ice. Impacts of climate change have not gone unnoticed at the community level and Inuit and other northern residents have reported dramatic changes in climate, weather, and landscape. Although scientific research has made a great deal of progress in understanding the present and potential impacts of Arctic climate change, climate change as observed, experienced, and explained through traditional and local knowledge in the North has received little attention.

Using a multi-method approach (semi-structured interviews, content analysis, participant observation, mapping), this project works with Inuit Elders and hunters to document and examine their knowledge of climate processes and change and proposes to develop a framework for cooperative sharing of Arctic climate change information between Inuit and scientists. The research is taking place with four Inuit communities in Nunavut, Canada: Iqaluit, Igloolik, Baker Lake, and Clyde River.

Inuit observations of climate change are often housed within knowledge of complex ecological and environmental processes and relationships. Through their detailed knowledge of these systems, Inuit report changes in climate and subsequent impacts to the landscape, for example, changes in seasonal characteristics and timing, storm frequency, snow and ice conditions, animal populations, and glaciers. Many observations are specific to certain communities, demonstrating regional differences of the impacts of Arctic climate change, as well as the precise nature of Inuit knowledge. Other observations, such as increased weather variability, are shared across the entire Canadian Arctic and even into Alaska. These changes are having an impact on Inuit life. Thinning ice has restricted travel, unpredictable weather has caused hunting parties to be unexpectedly trapped out on the land, and extremely low river levels have blocked access to traditional hunting areas.

The current phase of the project is focused on the collaboration of Inuit and scientific knowledge of climate change. Digital video and mapping technology is being used to illustrate Inuit knowledge, along with scientific observations, in an interactive CD ROM format.

An Integrated Assessment of the Impacts of Climate Variability on the Alaskan North Slope Coastal Region

Principal Investigator: Amanda H. Lynch

Co-Principal Investigators: Ronald D. Brunner, Judith A. Curry, James A. Maslanik, James P. Syvitski, University of Colorado-Boulder, Linda O. Mearns, National Center for Atmospheric Research, Anne Jensen, Glenn Sheehan, Ukpeagvik Inupiat Corporation

Theme(s): Regional Processes

Payoff: to enable the people of the North Slope coastal region to make more informed decisions in the face of climate variability, including changes in average temperatures, sea ice, permafrost and the frequency and intensity of extreme events.

Funding Source: NSF

The primary goal of the project is to help stakeholders on the North Slope of Alaska clarify and secure their common interest by exchanging information and knowledge concerning climate variability on seasonal and decadal time scales. To achieve this goal, we will apply an improved understanding and predictive capability of regional climate variability and change to generate a range of scenarios for changing sea ice variability, extreme weather events, storm surges, and other environmental factors. These scenarios can be used to predict the probability of states that affect coastal communities, surveys and management of marine mammals, marine transportation and offshore resource development. The project includes the following specific elements:

- Knowledge exchange with local stakeholder groups (primarily indigenous groups and government agencies) towards identifying important events and decision-relevant variables, and presentation of the information in a manner that is useful for economic and policy decision-making.
- Description and analysis of climate variability in the Alaskan North Slope coastal region on time scales from seasons to decades, including linkages between human, ecological, and environmental variables.
- Application of physical models to make detailed analyses of Arctic environmental processes and feedbacks and use of ensemble techniques to arrive at a plausible scenario space of climate variations on seasonal to decadal time scales.
- Application of ensemble simulations and data analysis to develop statistical models to support socioeconomic decision making on community developments, surveys and management of marine mammals, marine transportation and offshore resource development on the Alaskan coast.
- Development of an interdisciplinary graduate environmental education program that integrates the natural and social sciences with specific application to Arctic climate and socioeconomic issues.

The first phase of the project has commenced with a focus on extreme wind events in Barrow, which was discussed in meetings with local residents, including North Slope Borough officials and tribal elders, in August 2001. Increasing amounts of open water in the Arctic seas combined with rising sea level and changing coastal geography will contribute to increased harshness of weather events, such as the storm of August 10 last year, which delivered 65-knot winds to Barrow. Such storms often result in high winds, storm surge, flooding, and shoreline erosion.

The impacts of these storms, in combination with increasing development along the coastline, may include more damage in the future to buildings, roads, boat landings, airfields, utilities, equipment, and supplies of food, gasoline, and the like. In addition, the secondary impacts may include harm to animals and their land or sea habitats, if pollutants are released from a storage depot, sewage lagoon, or landfill. And of course, the impacts of more climate variability might include greater risks to human life and limb. Initial research is focusing on the decisions leading to the institution and subsequent abandonment of the Beach Nourishment Program by the North Slope Borough Assembly.

The Diurnal Climatology of Rainfall in Northwestern South America

Project personnel: B. Mapes, T. Warner, M Xu

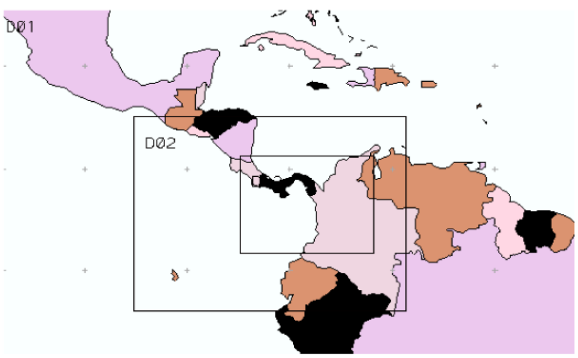
Theme: Regional Processes

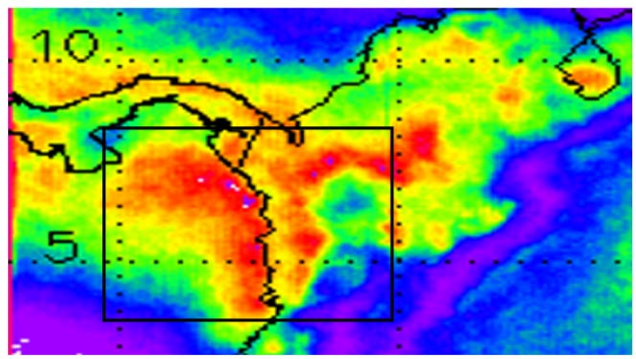
Payoff: Improved understanding of rainfall processes over complex geography

Funding source: NOAA

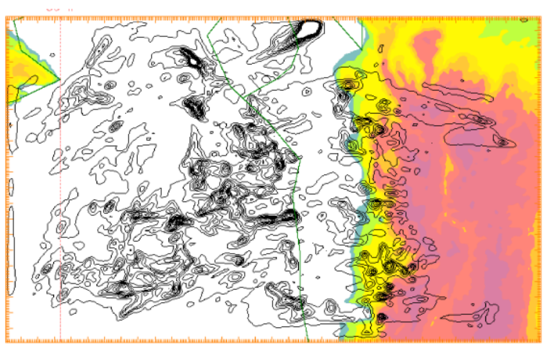
Rain falling in any one location reflects atmospheric processes occurring on many scales, from global to regional to local to cloud-scale. To investigate these processes, nested-grid modeling was used to create a simulation spanning the entire tropical Americas, yet with cloud-resolving (2km) grid spacing in an area of particular interest.

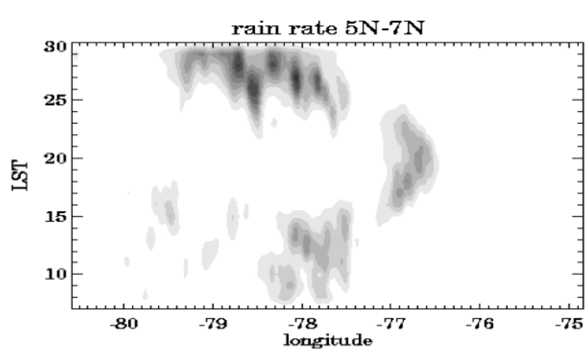
The domain of the simulation is shown below left. A satellite-derived annual rainfall climatology of the Panama-Colombia region (courtesy of Andy Negri at NASA) is shown at right, in a rainbow color scale with purple indicating low rainfall and red indicating high rainfall (>6000 mm/ year in the maximum!)





One interesting feature of the rainfall is the strip of local rainfall minimum (yellow) in the coastal plain between the offshore and inshore maxima (red) in the indicated box in western Colombia. The model successfully simulates this minimum, even when the coastal plain is perfectly flat and smooth (below left: color- topography, contours-daily mean rainfall). Time-longitude sections (below right) show that this minimum lies astride an asymmetric land-sea diurnal alternation. Sensitivity tests indicate that mountains are crucial: a land-sea thermal contrast is not enough.





Using the SHEBA Flux Data to Improve Regional and Global Climate Models

Project Personnel: A. Grachev, O. Persson, C. Fairall (NOAA/ETL), E. Andreas (CRREL), P. Guest (NPS), T. Horst (NCAR), J. Intrieri (NOAA/ETL)

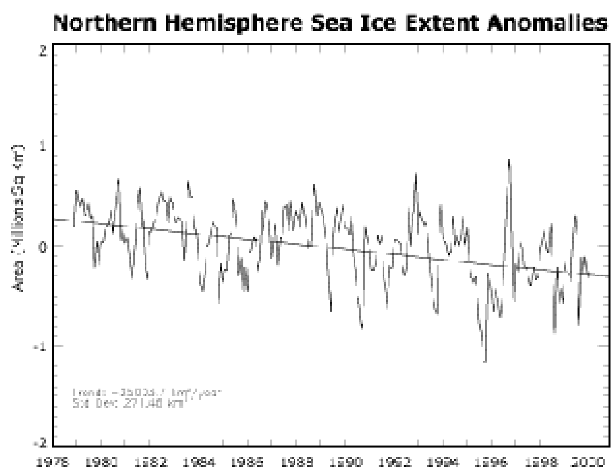
Theme(s): Regional Processes

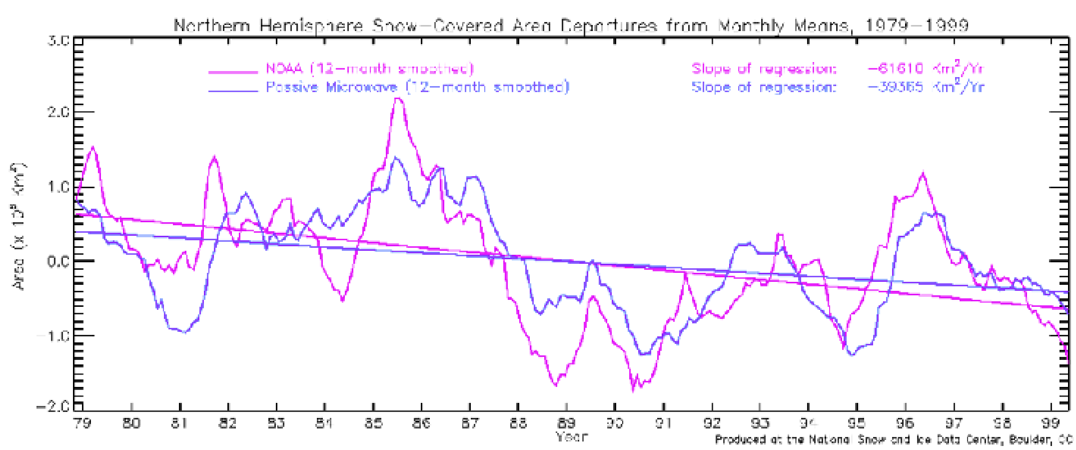
Payoff: Producing a high-quality, integrated data set of all relevant near-surface meteorological and flux variables to be used for improving regional and global climate models (GCMs) over the Arctic pack ice.

Funding Sources: NSF, NOAA

The Surface Heat Budget of the Arctic Ocean (SHEBA) data set collected on the Arctic pack ice has revealed measurement limitations and physical processes that will impact the accuracy of parameterizations derived from this data. One surprising finding is that clouds act to warm the ice surface during the entire year, except for a few weeks after the summer solstice. That is, the ability of clouds to trap long wave radiation is more important to the surface energy budget (SEB) than is their ability to reflect shortwave radiation. The measurements also show that the Arctic surface layer is saturated with respect to ice throughout most of the year, and simple modeling suggests that the moisture flux from leads and the presence of strong radiative surface cooling are the main reasons.

In all cases in the Northern Hemisphere, regardless of parameter or measurement method, the amount of snow and ice has been decreasing over the past several decades. Figure 1 presents trends in snow cover extent for the Northern Hemisphere derived from two different satellite sensors (visible and passive microwave). Both data sources indicate that the total snow cover extent has been decreasing by about 2 percent per decade. Figure 2 provides a similar time series for Northern Hemisphere sea ice extent derived from passive microwave data. These results indicate a decrease in area of about 3 percent per decade. In contrast, the Antarctic sea ice extent appears to have increased in area by slightly more than 1 percent over the same period.





Ozone Production in Power Plant Plumes and the Impact on Regional Air Quality

Project Personnel: Fred Fehsenfeld, John Holloway, Gerd Hübler, Donna Sueper

Theme(s): Regional Processes

Payoff: Improved information to assist energy industry decision-making to reduce air quality impacts

Funding Sources: NOAA

Research involving CIRES/NOAA scientists has uncovered new factors that could enhance future programs for cleaning up the air downwind of the Nation's electrical power plants.

The researchers flew highly instrumented research aircraft into the plumes downwind of power plants in 1999, measuring a host of chemical components in the air at several distances from the plants. By careful comparisons of various power plants in the eastern U.S., the researchers showed that with respect to air quality impacts, "all power plants are not created equal". The amount of ozone "smog" produced from the plumes was dependent on both the size and the geographic location of the power plants.

Fossil fuel-powered electrical generating plants emit nitrogen oxides, or "NOx", as a result of their burning of fossil fuel. In the presence of sunlight, the NOx can combine with volatile organic compounds (VOCs) in the atmosphere to make ozone pollution. High abundances of ozone at Earth's surface are harmful to human health and damaging to crops and forests.

In the U.S., power plants are responsible for about one-fourth of the human-made emissions of NOx pollution. Ozone formation downwind of power plants can elevate ozone levels on a multi-State scale, making compliance with existing and proposed ozone standards difficult.

Environmental policies are addressing this issue. Proposed new regulations would "cap" the amount of NOx emitted from the Nation's power plants, and permit individual plants to "trade" emission credits to minimize costs. Proposed regulations are projected to reduce the NOx emissions from power plants by about 8% nationwide.

The new study found that if a power plant were located in a region where the surrounding air contains a large amount of VOCs, the power plant's NOx emissions would make more ozone pollution than a similar plant located in a region with low amounts of VOCs. VOCs come from both natural sources (such as the isoprene emitted by trees) as well as human-made sources (such as automobile usage). Coincidentally, many of the Nation's power plants are located in the eastern U.S., where the terrain is heavily wooded and the levels of natural VOCs are high.

The study also found that bigger power plants make less ozone per ton of NOx emitted compared with smaller power plants. In the plume of big power plants, the high-NOx environment promotes a series of chemical transformations that suppress the formation of ozone.

This research is timely scientific input for current efforts to address the Nation's future energy needs; in that it demonstrates that decisions regarding the size and location of power plants could be tailored to help States and localities achieve their goals for air quality improvement.

Large power plant located in Tennessee.

Application of Lidar Profiling in Regional Air Quality Studies

Project Personnel: C. J. Senff, R. M. Banta, L. S. Darby, R. J. Alvarez, S. P. Sandberg

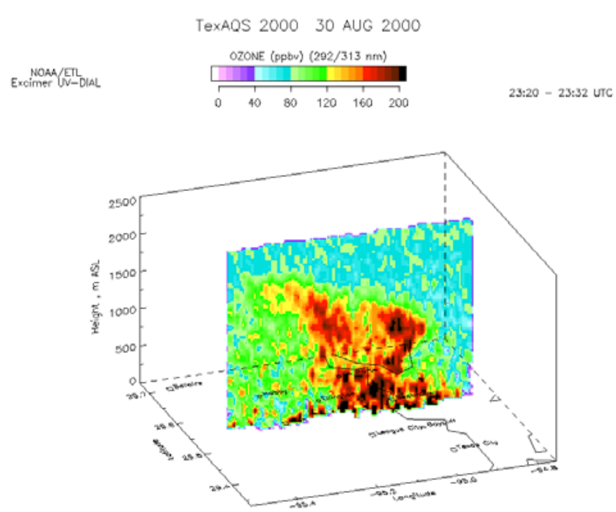
Theme(s): Regional Processes

Payoff: Improved understanding of processes controlling regional air quality

Funding Source: NOAA

Knowledge of the vertical distribution of pollutant concentrations in the lowest few kilometers of the atmosphere is crucial for predicting their evolution near the surface. As the boundary layer grows in the morning, layers of pollutants that may be present aloft will be mixed down to the surface resulting in an increase of pollutant concentrations. Elevated pollution layers have been observed in many locations; they are either remnants of the previous day's polluted boundary layer or have been advected from distant sources.

Pollutant profiles, especially ozone and aerosol, can be measured with lidar remote sensors. In recent years, NOAA/ETL has deployed its ozone and aerosol lidars during several regional air quality studies, most recently at the Texas Air Quality Study in the summer of 2000. The objective of this study was to investigate the chemical and meteorological processes that cause the extreme ozone pollution episodes observed in the Houston, TX area. Measurements with NOAA/ETL's airborne ozone lidar showed that pollutants released into the nighttime offshore flow were transported over Galveston Bay and the Gulf of Mexico. There they formed plumes of high ozone concentrations that were confined to the shallow marine boundary layer. As the flow reversed with the onset of the afternoon sea breeze, these plumes of high ozone were transported back to the Houston area where they further increased the already high pollutant levels in the Houston urban plume. The airborne lidar measurements also revealed that pollutants were pushed upwards to the top of the boundary layer near the sea breeze front due to additional lift in the sea breeze convergence zone. The figure below shows the horizontal and vertical distribution of ozone across the sea breeze convergence zone south of the Houston metro area on the afternoon of August 30th 2000. Ozone concentrations of up to 200 ppbv were confined to the lowest 500 m over Galveston Bay but extended up to 2 km above ground in the sea breeze convergence zone west of Galveston Bay. The presence of these very high ozone concentrations at elevated levels has important implications for regional air quality: since elevated ozone layers are not destroyed at night they become available for nocturnal long-range transport and may increase regional background ozone levels as they are entrained into the next day's boundary layer.



Lagrangian Modeling of Dispersion in the Convective Boundary Layer

Project Personnel: J.C. Weil, P.P. Sullivan (NCAR), C.-H. Moeng (NCAR)

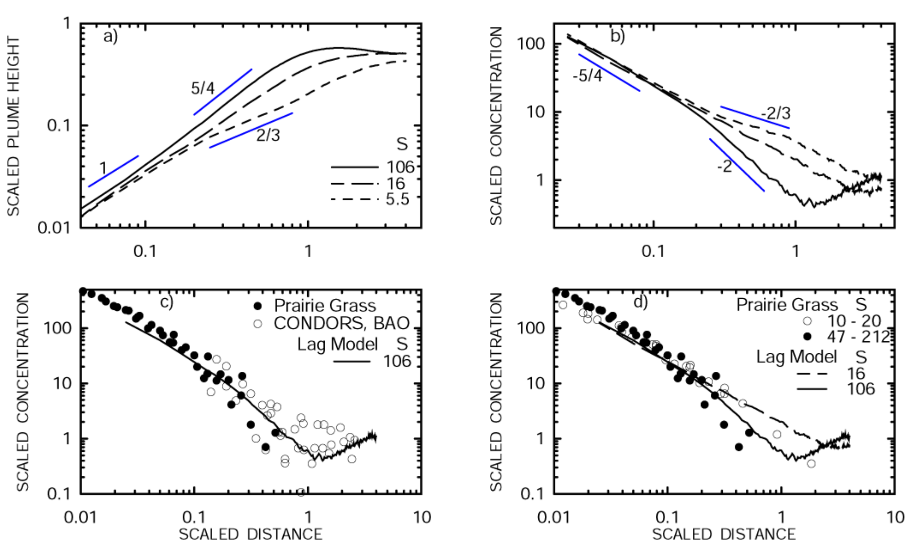
Theme: Regional Processes

Payoff: Improved dispersion parameterization for air quality and land/surface exchange

Funding Source: Army Research Office

Dispersion in the convective boundary layer (CBL) depends on the CBL mean and turbulence structure, which varies with the surface heating and mean-wind shear. In strong convection, the turbulence is dominated by intense updrafts, whereas in weak convection with strong shear, the near-surface turbulence is marked by strong "streaky" motions. The CBL turbulence can be characterized by the stability index $S = -z_i/L$, where z_i is the CBL depth and L is the Monin-Obukhov length---the depth over which surface friction or shear-driven turbulence is important. Strong convection exists for S > 100 and weak convection for S of order 1. The marked difference in turbulence properties with stability can have profound effects on atmospheric dispersion, air quality, and trace gas exchange. However, there are no numerical simulations and few field observations detailing the dispersion properties over a broad range of stability or S.

A numerical investigation of the dispersion characteristics for a surface source in the CBL was conducted using a Lagrangian "particle" model driven by velocity fields from large-eddy simulations (LES). The LES fields were obtained for a 5 km × 5 km × 2 km domain with S = 106, 16, and 5.5. The results showed that the mean plume height, vertical dispersion, and surface concentration varied significantly with both the scaled downstream distance and S. For short distances, the plume height and surface concentration were nearly independent of S, but for greater distances the results exhibited significant variation with S. For strong convection, the modeled surface concentration followed the average trend of observations from the Prairie Grass and Boulder Atmospheric Observatory (BAO) field experiments. Fewer data were available for checking the stability dependence of the model. However, the Prairie Grass data, although limited in extent and scattered, qualitatively supported the model predictions in two S groupings.



Lidar Measurement of Ammonia Concentrations and Fluxes in a Plume from a Point Source

Project personnel: Yanzeng Zhao, Alan Brewer, Wynn Eberhard, and Raul Alvarez

Theme(s): Regional Processes

Payoff: The first reported experiment using a coherent CO_2 lidar for remote sensing ammonia

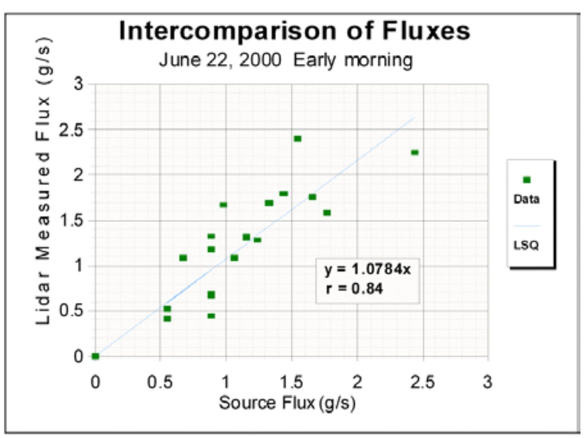
Funding Sources: CARB and NOAA

The issue about formation and transport of secondary aerosol particles from anthropogenic processes has been a new focus of controlling aerosol pollution, which is harmful to public health. In a polluted urban environment ammonium nitrate can account for a significant percentage of the fine aerosol mass, and ammonia is one of the most important gas-phase precursors of ammonium nitrate aerosols. Measurement of ammonia concentrations can play a key role in evaluating the emission of sources and understanding the formation of ammonium nitrate particles from gas phase precursors.

The existing techniques for measuring ammonia concentrations are mostly restricted at the surface, and not range-resolved. Lidar is the only remote sensing instrument that can measure one to three dimensional ammonia concentration distributions for air quality studies with much needed temporal and spatial resolution.

The NOAA Environmental Technology Laboratory's mini-MOPA (master-oscillator-power-amplifier) CO_2 Doppler lidar is a coherent lidar that detects wind and aerosol backscatter in the atmosphere. With recently developed dual-laser and fast-tuning techniques, it is also capable of measuring concentrations of molecular species in a differential absorption lidar (DIAL) operation. Special advantages of using this Doppler lidar for DIAL measurements are the narrow line width and excellent frequency stability, which are crucial for obtaining a good accuracy of the measurement.

We performed a field experiment that demonstrated the capability of the mini-MOPA lidar in measuring ammonia concentrations in a plume from a point source. Good agreement between the source fluxes measured by a flowmeter and the lidar-measured flux 1 km downwind was obtained. As far as we know, it has been the first reported experiment in which a coherent lidar system measured ammonia concentrations using atmospheric backscattering signals.



This lidar system is going to be substantially modified for operating at a wavelength pair that is sensitive of measuring ambient ammonia concentrations in polluted areas.

Large Particles Containing Nitric Acid Found in Stratosphere

Project Personnel: John Holecek, Andrew Neuman, Peter Popp, Megan Northway

Theme(s): Regional Processes

Payoff: Important new information for understanding stratospheric ozone depletion

Funding Sources: NOAA

A newly discovered class of particles has given scientists a better understanding of the processes that "set the stage" for chlorine-caused ozone depletion in the stratosphere above the Arctic.

Icy, nitric acid-containing "polar stratospheric cloud" (PSC) particles are formed in the polar regions during winter, where they enhance the destruction of ozone by human emissions of chlorine and bromine. The newly discovered particles have diameters of 10-20 microns (millionths of a meter), which is about 10-20 times larger in diameter than typically observed in PSCs. These particles have eluded detection to date because of their unexpectedly large size and very small abundance in the atmosphere.

The PSCs are laden with nitric acid (HNO3) and thus serve as reservoirs for reactive nitrogen in the polar stratosphere. As the particles sediment, or fall out of the atmosphere, the stratosphere becomes "denitrified". The loss of reactive nitrogen has consequences for ozone, because ozone-destroying forms of chlorine and bromine are longer-lived in a denitrified stratosphere. The discovery of this new class of large PSC particles helps to explain a longstanding mystery, namely, that the extent of de-nitrification observed in the polar stratosphere could not be accounted for by the smaller (and slower-to-sediment) PSCs.

CIRES scientists along with their colleagues from NOAA, NASA and other universities made the observations in the Arctic winter stratosphere of January-March of 2000. Instruments onboard the NASA ER-2 high-altitude research aircraft measured reactive nitrogen species as the aircraft traveled toward the Pole and deep into the region of highest ozone loss.

The large-sized PSCs observed in some of the air samples contained 15-20% of the available reactive nitrogen in the Arctic stratosphere, and were falling at a rate of 1-2 kilometers per day. These values demonstrate the potential for significant de-nitrification by these large particle populations. The 2000 Arctic winter stratosphere was extensively denitrified, which set the stage for significant chlorine- and bromine-caused ozone loss in the winter and spring.

Cold temperatures promote the growth of large PSCs and thus enhance the loss of ozone by chlorine and bromine. Unusually cold winters, or climate shifts that reduce stratospheric temperatures or alter the amount of water vapor in the stratosphere, could prolong chemical ozone loss in the Arctic even as chlorine levels fall in response to international curtailments in the use of ozone-depleting chemicals.

Photo of polar stratospheric cloud.

Light-Initiated Atmospheric Radical Formation at Low Energy

Project Personnel: D.J.Donaldson, A.F.Tuck, V.Vaida

Themes: Regional Processes; Planetary Metabolism

Payoff: Provide new mechanisms for atmospheric radical production at high zenith angles. Use this information to interpret results of field measurements of OH during POLARIS

Funding Sources: NOAA, NSF

Chemistry in the atmosphere is initiated and driven by energy from the Sun, which is capable of braking molecular bonds to generate reactive radicals. Light-initiated chemical reactions included in standard atmospheric models require high-energy ultraviolet radiation, which excites electronic molecular states and leads to chemical bond fission.

In an interdisciplinary effort, partially funded by the NSF, we proposed and quantified a new set of photochemical processes where excitation of vibrational rather than electronic states, at much lower energy, leads to radical formation in the atmosphere. These reactions are especially important at dusk, dawn and at the edge of the polar vortex, where red but not ultraviolet light is available. Our findings explain some of the discrepancies between model deduced and airborne field measurements (POLARIS) of reactive species such as OH and HO_2. As a result of this work, inclusion in the new NASA compilations used for atmospheric modeling of relevant vibrational cross sections is being considered.

Lagrangian Modeling of Dispersion in the Convective Boundary Layer

Project Personnel: J.C. Weil, P.P. Sullivan (NCAR), C.-H. Moeng (NCAR)

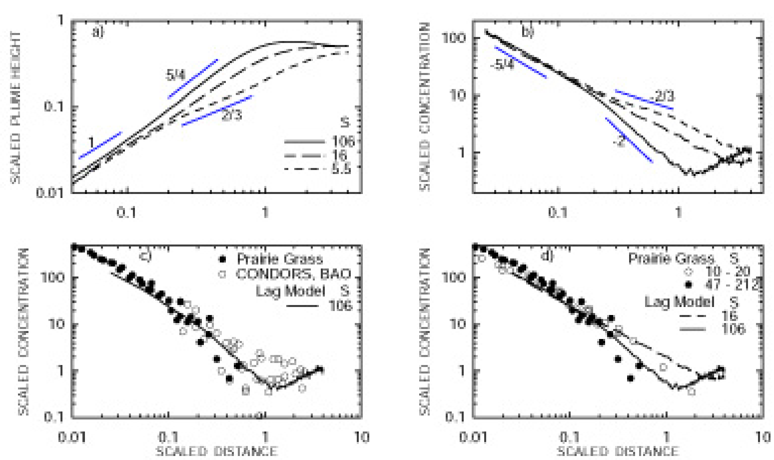
Theme(s): Regional Processes

Payoff: Improved dispersion parameterization for air quality and land/surface exchange

Funding Source: Army Research Office

Dispersion in the convective boundary layer (CBL) depends on the CBL mean and turbulence structure, which varies with the surface heating and mean-wind shear. In strong convection, the turbulence is dominated by intense updrafts, whereas in weak convection with strong shear, the near-surface turbulence is marked by strong “streaky” motions. The CBL turbulence can be characterized by the stability index $S = -z_i/L$, where z_i is the CBL depth and L is the Monin-Obukhov length---the depth over which surface friction or shear-driven turbulence is important. Strong convection exists for S > 100 and weak convection for S of order 1. The marked difference in turbulence properties with stability can have profound effects on atmospheric dispersion, air quality, and trace gas exchange. However, there are no numerical simulations and few field observations detailing the dispersion properties over a broad range of stability or S.

A numerical investigation of the dispersion characteristics for a surface source in the CBL was conducted using a Lagrangian “particle” model driven by velocity fields from large-eddy simulations (LES). The LES fields were obtained for a 5 km × 5 km × 2 km domain with S = 106, 16, and 5.5. The results showed that the mean plume height, vertical dispersion, and surface concentration varied significantly with both the scaled downstream distance and S. For short distances, the plume height and surface concentration were nearly independent of S, but for greater distances the results exhibited significant variation with S. For strong convection, the modeled surface concentration followed the average trend of observations from the Prairie Grass and Boulder Atmospheric Observatory (BAO) field experiments. Fewer data were available for checking the stability dependence of the model. However, the Prairie Grass data, although limited in extent and scattered, qualitatively supported the model predictions in two S groupings.



Measurements and Modeling of Ozone Air Quality at La Porte Airport During TEXAQS-2000

Project Personnel: E. J. Williams, S. McKeen, P. C. Murphy, D. Hereid, F. C. Fehsenfeld

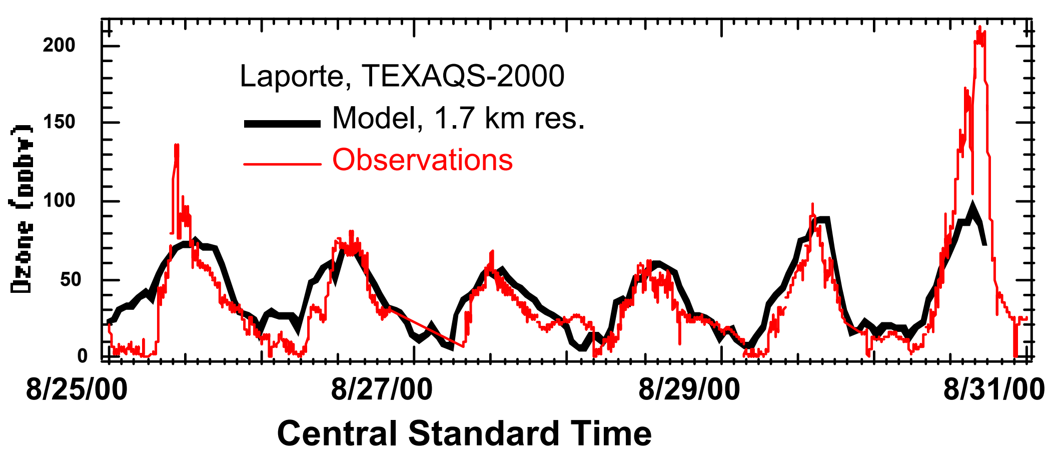
Theme(s): Regional Processes

Payoff: Providing a photochemical data set for testing air quality forecasting models

Funding Sources: NOAA, TNRCC

Air quality forecasting is rapidly becoming as essential as weather forecasting, especially in the nation's most polluted cities. At-risk groups in urban areas can benefit substantially from predictions of potentially unhealthful levels of pollutants such as ozone. Of principal concern, however, is the accuracy with which these predictions can be made. Improvements in available computational power have increased the resolution of air quality prediction models, but an accurate representation of the primary emissions and the photochemistry in these models remains a fundamental requirement. A principal means of testing the output of these models is by comparison to simultaneous measurements of the most important photochemical trace species. Intensive measurement campaigns that utilize state-of-the-art instrumentation to probe atmospheric photochemistry have been conducted in the past by CIRES/Aeronomy Laboratory personnel, most recently in the Houston, TX, region as part of the TEXAQS-2000 study during August and September, 2000.

Data collected at the La Porte Airport site was used as part of an evaluation of air quality forecast models. Comparison of modeled data to that observed provides insight not only into the accuracy of the photochemical mechanism in the models, but also can be used to infer the quality of the emissions database used. This latter point is especially important for the heavily industrialized Houston region. The figure below shows the comparison of predicted ozone to that measured at La Porte. In general, the model reproduces ozone levels very well which provides a measure of the quality of the photochemistry in the model. However, the comparison of other trace gases such as carbon monoxide, a species that is both emitted and produced photochemically, was not as good. Discrepancies such as these may be due to inaccurate emissions representation in the models. These investigations are ongoing.



Research Theme: *Geodynamics*

At its most basic level, the goal of geodynamics is to better understand the process of convection within the Earth's mantle, and of how that convection affects the surface of our planet. The mantle, which extends from the top of the Earth's liquid core at a spherical radius of about 3500 km up to the Earth's surface at a radius of about 6400 km, behaves as a solid at the time scales over which we live, but convects as though it were fluid over geological time scales. The convective motion, which is on the order of a few cm per year, causes oceans to open and close, continental plates to drift across the earth's surface, and the Earth's crust to buckle and deform creating mountain ranges and other structural features. The convective displacements are the underlying source of earthquakes and volcanic activity. In fact, in an indirect but very real sense, this convective process even plays a fundamental role in determining the Earth's climate, through its impact on surface topography.

Why this is Important

Most of the fundamental issues concerning the convection remain poorly understood. What dynamical processes and structural parameters determine the style and vigor of the convection? How well known are the values of the important structural parameters (e.g. mantle viscosity, plate thickness), as estimated using independent geophysical observations? How are the motions of surface plates related to flow in the deep mantle, and what can be learned about convection and tectonic processes by measuring that motion? How is the Earth layered, and what are the tectonic implications of that layering? What is the origin of various near surface geological and geochemical features (e.g. mountain ranges, magma bodies), and what do those features tell us about mantle dynamics? What determines earthquake magnitudes and recurrence times? How does the slip along a fault evolve with time during the earthquake?

GPS, absolute gravity, and other geodetic measurement techniques are being employed in the field and from space to detect tectonic motion at all scales; from the large-scale motion of plates relative to one another, to the regional deformation within individual plates and near plate boundaries, to the local motion associated with slip on individual faults. Seismic observations are being used to map out the Earth's internal structures in different regions of the globe, at depths ranging from the near surface down to at least the mid-mantle, and to estimate the characteristics of individual earthquakes (e.g. location, magnitude, slip vector). In the lab, field samples are being analyzed by isotope geochemistry to understand the process of continental evolution. The properties of rocks at high pressures and temperatures are also being studied to probe relationships between the geodynamics and wave velocities that a seismologist actually measures. Dynamical models are being employed to determine the effects of the Earth's rheological properties on various types of tectonic motion, model the mountain building process, and to improve our understanding of the fundamental, non-linear behavior of earthquakes and earthquake cycles.

The role the uplift of the Himalayan Mountains may have played in initiating the Asian monsoon cycle is being studied. The application of geochemical dating methods to ice cores is providing information on long-term global change. Results from seismic wave speeds in rocks are suggesting the possibility of using field seismic data to monitor the spread of ground water contaminants. Field geodetic measurements in southwestern Greenland indicate that its ice sheet margin is likely to have advanced by 10's of kms over the last few thousand years. Gravity measurements from satellites originally intended to probe into the solid Earth will provide even more valuable information on regional, temporal variations in such things as ocean bottom pressure, the distribution of water stored on continents, and the mass imbalance of the polar ice sheets.

Geodesy in Greenland

Project Personnel: J. Wahr, T. van Dam, K. Larson, O. Francis, S. Gross

Theme(s): Geodynamics

Payoff: Characterization of paleo ice sheet movement to assist understanding of current climate trends

We have been using geodetic measurements of crustal motion in Greenland to put constraints on both the present day mass imbalance and the late Holocene deglaciation of the Greenland ice sheet. We have installed two permanent GPS receivers at bedrock locations along the margin of the Greenland ice sheet to measure crustal motion. Changes in gravity have been determined by also making absolute gravity measurements at those locations. We have found that by combining the GPS and gravity results it is possible to separate the effects of loading caused by present-day changes in ice from the effects of the Earth's visco-elastic response to Holocene de-glaciation. We have discovered an unexpectedly large rate of crustal subsidence along the southwestern ice sheet margin. Our efforts to model this subsidence have lead us to conclude that the ice sheet in that region may have advanced by about 50 km during the last 3,000-4,000 years.

Research station in Greenland.

Role of the Upper Mantle in Driving Surface Tectonics

Project Personnel: H. J. Gilbert, A. F. Sheehan, and P. Molnar

Theme(s): Geodynamics

Payoff: Verification and diagnostics of global climate model projections in support of IPCC and National

Funding Sources: NSF, CIRES

Considerable progress has been made towards understanding the forces driving plate tectonics and their relationship to processes such as mountain formation and earthquake faulting. However, little is known about the role of sub-asthenospheric mantle on the driving forces of plate tectonics. Recent increases in the number of seismic receivers on Earth's surface, along with advances in data processing techniques have allowed for investigation of the mantle at previously unattainable scales. These improvements in seismic data and coverage are providing insight into Earth structure and composition. Abrupt increases, or discontinuities, in seismic wave speeds at the nominal depths of 410 and 660 km within the mantle, which are thought to result from phase transitions, serve as markers to study variations in thermal and compositional structure. We have undertaken studies of the upper mantle in the regions of the Tonga subduction zone and western United States to gain understanding of what role the mantle may contribute to these diverse tectonic regions.

The upper mantle discontinuities in the region of the Tonga slab appear perturbed by cold material as would be expected near a subduction zone. The 410-km discontinuity is uplifted to shallower depths by 30 km and the 660-km discontinuity deepens by 20-30 km. The horizontal extent of variations in the depth of the 660-km discontinuity suggests that the slab encounters resistance to penetrating deeper and may be piling up on top of the discontinuity. Below the western United States we image similar amounts of discontinuity topography. Variations in discontinuity depths do not correlate with the Rocky Mountains, Colorado Plateau, or Basin and Range Province suggesting that shallower forces drive tectonics in these regions. The amount of discontinuity topography found in this region implies the presence of a similar thermal perturbation that may be related to lateral temperature variations due to convective flow. In addition, no correlation in discontinuity depths is found in the western United States. This may indicate differing thermal variations at each discontinuity and upward or downward flow across one discontinuity not crossing the other. The topography on both the 410- and 660-km discontinuities possess a characteristic wavelength near 800 km, which is roughly twice the thickness of the asthenosphere to these depths. Observations made here suggest that convective flow causing deflections of the 410-km discontinuity is confined to the upper mantle.

Investigations of the Interrelationship between Continental Volcanism and Tectonism

Project Personnel: G. Lang Farmer

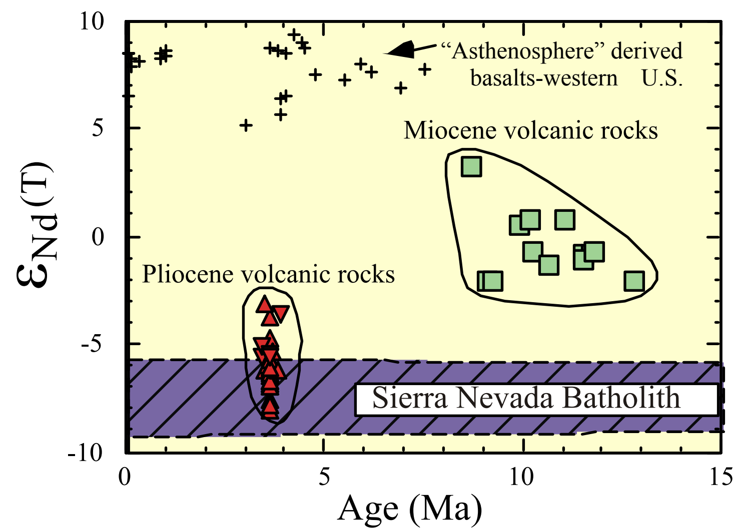
Theme(s): Geodynamics

Payoff: Fundamental insights into the evolution of the deep continental lithosphere

Funding Sources: NSF, DOD

It has long been recognized that deformation of the Earth's continental lithosphere can lead to magmatism, but the exact mechanisms involved in magma production remain obscure. Western North America is an ideal natural laboratory for investigations of the trigger mechanisms of continental magmatism, due to the widespread occurrence of Late Cenozoic magmatism in this region. Our studies involve age, chemical and isotopic studies of basaltic magmatism in the Basin and Range of the U.S. and Mexico with intent of assessing the relationship between tectonism and magmatism. The data are being incorporated, along with existing volcanic rock geochemical data, into a North America Volcanic Database (NAVDAT). The development of the latter was funded in 2001 through joint funding by DOD and the Information Technology (IT) program at NSF.

Our ongoing studies of Late Cenozoic potassic volcanism in the central Sierra Nevada, California, funded through the Continental Dynamics (CD) Program at NSF, provide an example of how volcanic rock geochemical data can provide insights into the tectonic development of the deep continental lithosphere. Our data demonstrate that a profound difference exists in the chemical and isotopic characteristics of Miocene (~8-12 Ma old) and Pliocene (~3.5 Ma) volcanic rocks, including their neodymium isotopic compositions (below diagram). These differences require a change from a deep continental lithosphere or asthenosphere magma source for the older volcanic rocks to a shallow mantle lithosphere source for the younger rocks. Combined with other geologic data, our observations support a model in which Pliocene magmatism was triggered by delamination of the deep continental lithosphere, which exposed the remaining shallow mantle lithosphere to hot, upwelling asthenosphere. Delamination of the deep lithosphere may also have been responsible for the Pliocene pulse of uplift documented in the southern Sierra Nevada.



Earthquake Fault Zone Studies

Project Personnel: C. Jones, A. Sheehan, P. Molnar, C. Wilson

Theme(s): Geodynamics

Payoff: Improved Earth subsurface images of earthquake faults, earthquake hazards

Funding Sources: NSF, New Zealand Marsden Fund

Between December 2000 and July 2002, fifty short period and seven broadband sensors are deployed across the Marlborough Fault Zone of the South Island, New Zealand, in an effort to test competing conceptualizations of continental boundary deformation using seismic converted phase analysis. Such models can range from a narrow, near-vertical plate boundary through the entire lithosphere to a broad deforming zone. Observations of offsets of discontinuities across these faults and anisotropy in the lithosphere will distinguish among the possibilities. The Marlborough region, containing four main faults, was chosen because it is an active, well-developed, continental strike-slip boundary that accumulated ~460 km of slip over the last 12 million years. Most of the net slip is on the northernmost strand, the Wairau Fault, but Holocene slip rates are higher on the more southerly strands of the fault zone. In addition, the region experiences both abundant local intermediate depth seismicity (providing high-frequency body waves with steep angles of incidence) and well distributed teleseismic events. Sensors have been deployed in five L-shaped arrays and three freestanding broadband seismometers along a transect from north of the Wairau Fault to near the Awatere Fault; a second deployment will carry across the remaining faults of the system. Beams of short period seismograms are constructed to reduce the effect of scattering from topography in the region; these are then used to construct receiver functions. Variations in depth of Moho, amplitude and timing of radial and transverse arrivals constrain whether the deeper levels of the plate boundary are discrete or not. Broadband stations provide additional frequency range to examine possible frequency dependence of conversions and anisotropy.

Archive Studies of Indian Earthquakes (NSF 1998-2001)

Project Personnel: R. Bilham

Theme(s): Geodynamics

Payoff: Improved knowledge of future damaging earthquakes

Funding Sources: NSF

The historic record of earthquakes in India extends back more than 2000 years but it is only in the past two centuries that instrumental estimates of rupture location, area and intensity have become available. Hitherto the sources of data for these recent earthquakes have been secondary compilations or catalog information. In the past three year years the PI has examined original archives in London, Oxford, Calcutta, Delhi and Dehra Dun in order to obtain primary data to quantify the parameters of these earthquakes. The earliest and reportedly the most catastrophic of Indian earthquakes in the colonial records is one that was reported in 1737 in Calcutta. This event was found to be not an earthquake, but a cyclone with a much-exaggerated death-toll. Using early canal survey records from 1844, the 1819 Allah Bund earthquake in Kachchh was inferred to be an M=7.8 reverse slip event. An earthquake in Nepal in 1833 that affected a similar area to the 1934 earthquake was assigned M=7.8 based on felt intensity data. Tide gauge records surrounding a submarine earthquake in the Andaman islands in 1881 were used to infer the location, depth, rupture area and amount of slip of a M=7.9 earthquake. Using century old geodetic data we determined the rupture parameters of the great M=8.1 Assam earthquake to have resulted from ≈15 m uplift of the Shillong Plateau. Using recalibrated seismic records from Europe, and local geodetic data, the 1905 Kangra earthquake was determined to be an M=7.8 event with a rupture area smaller than believed hitherto. Partial studies were completed of the 1803 Kumaon earthquake, and events in Kashmir and Bhutan. The net result of these studies and recent geodetic findings is that it has become possible quantify the current slip potential for future great earthquakes along the Himalayan arc. Seven regions are currently loaded sufficiently to drive an earthquake with the severity of the 1934 Bihar/Nepal event.

Phase Dynamical Probability Change (PDPC) Analysis of Southern California Fault Systems

Project Personnel: J.B. Rundle, K.F. Tiampo, S. McGinnis

Theme(s): Geodynamics; Advanced Observing and Modeling Systems.

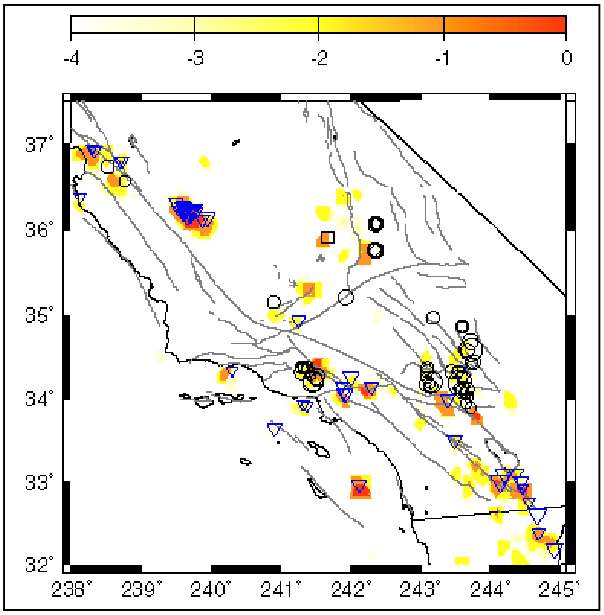
Payoff: Improved understanding of earthquake fault systems and earthquake forecasting models.

Funding Sources: DOE, NASA

Large, extended fault systems such as those in California demonstrate complex space-time seismicity patterns, which include repetitive events, precursory activity and quiescence, and aftershock sequences. Although the characteristics of these patterns can be qualitatively described, a systematic quantitative analysis remains elusive. While studying the physics of these fault systems, a new pattern dynamics methodology was developed in order to define a unique, finite set of seismicity patterns for a given fault system, similar in nature to the empirical orthogonal functions historically employed in the analysis of atmospheric and oceanographic phenomena. This pattern dynamics technique has been successfully applied to numerically modeled seismicity for fault networks similar in character and extent to those found in California, and to historical seismicity in California and derive space-time eigenvalue patterns for the San Andreas fault system.

These results, and realistic numerical simulations of earthquakes, suggest that earthquakes are characterized by strongly correlated space-time dynamics, leading to the development of a method for identifying areas of increased probability of an event, $\Delta \mathbf{P}$. The PDPC procedure is based upon the idea that seismic activity corresponds geometrically to the rotation of a pattern state vector in the high-dimensional correlation. This figure shows $\Delta \mathbf{P} > 0$, using only existing seismicity data acquired *prior* to January 1, 1992, six months before the occurrence of the Landers earthquake sequence.

The increase in $\Delta \mathbf{P}$ above the background level should be interpreted as the formulation of a spatially coherent region of either anomalous activation or quiescence, associated with an increased chance of a major earthquake. The color-coding is logarithmic. The inverted triangles represent events that occurred during the time period covered by the plot. Superimposed on this map are the locations of main shocks larger than 5.0 that occurred during the 8 years *following* the time interval from which we computed the probabilities. Black circles denote these locations. One can observe an obvious correspondence between regions of increased probability and the location of the subsequent main shocks, tending to support the results first observed in our simulations.



X-Ray and Neutron Beam studies of Earth Materials at High Pressure and Temperature

Project Personnel: Ivan C. Getting

Theme(s): Geodynamics

Payoff: Understanding of the dynamic behavior of earth materials.

Funding Sources: NSF, Center for High Pressure Research (CHiPR)

Geodynamics is the study of the internal motions of the earth. When you first see a grasshopper you learn quite a bit. If you watch him jump you learn a great deal more. From studies of the motions of the earth we also learn a great deal more.

The interior of the earth oscillates and flows in response to the forces within. This dynamic behavior is an expression of the forcing fields and the properties of the materials from which the earth is made. Unfortunately, the forcing fields and the material responses are inexorably coupled in the earth and we do not independently know either very well. In the laboratory, however, we can subject earth materials to known stress fields at known pressures and temperatures and observe the response. The only difficult part is generating and knowing the stress field, the pressure, the temperature, and observing the response.

Recently X-ray and neutron beams have been introduced into high pressure, temperature environments and provide much of the needed information. These probes allow us to observe the atomic arrangement of samples from the scale of lattice spacing to small crystals. This allows us to determine crystal structures, and with the most modern facilities, to study the kinetics of structural phase transitions in crystals. Phase transitions are vitally important in understanding the dynamics of the earth as they change volume, absorb or release energy, buffer pressure and temperature, and strongly affect the behavior of rising or sinking material within the earth. With X-rays we can also monitor pressure by observing the atomic spacing in a reference material for which the equation of state is know. The length of a shortening sample subjected to compressive differential stress can be monitored by the X-ray scattering from metal foils at the ends of the sample. Differential stress can be monitored by measuring the distortion in an elastic reference material in the same stress field as the sample. X-ray tomography permits us to determine the three dimensional morphology of partial melts in polycrystals vital to understanding the upwelling of magma at oceanic ridges. Neutron studies reveal the crystal orientation structure of polycrystalline materials undergoing deformation important in understanding rock deformation. The list goes on and on.

I serve as an advisor and a principal designer in the unique field of high-pressure instrumentation. Instruments of my design are in place in, under construction for, or proposed for six national laboratories facilities where these powerful X-ray and neutron beamlines are concentrated. Many of the fundamental design concepts are developed and tested in my laboratory at CIRES. Additionally at CIRES I work in high pressure metrology assuring that the measurements made in these difficult environments are made with the highest possible accuracy.

We are inventing ways to understand how the grasshopper jumps.

Absolute Gravimeter Helium Immersion Experiment

Project Personnel: D.S. Robertson, N. Courtier, and D. Winester

Theme(s): Geodynamics; Advanced Observing and Modeling Systems

Payoff: Improved gravity and gravity gradient measurements

Funding Sources: NOAA, Geologic Survey of Canada

The FG5 absolute gravimeter uses a laser interferometer to measure the acceleration of a free-falling mirror in a vacuum chamber. The recoil caused by the release of the falling mirror produces vibrations in the gravimeter that can systematically affect the measured gravity values. The major effect of the vibrations is to change the vertical position of the window on the vacuum dropping chamber where the laser interferometer beam enters the chamber. Because the window represents an air-vacuum interface, any motion of the window will change the fraction of the laser path that passes through air and thereby change the total time that the laser beam takes to traverse the interferometer path. Therefore these vibrations will have the same effect on the measured interferometer phase as changes in the position of the falling mirror.

The refractivity change across the air-vacuum interface can be significantly reduced by displacing the air with a gas whose refractivity is less than air. The best gas for this purpose is helium, which has a refractivity about 12% that of air. No other commonly available gas has refractivity as low. In other words, by immersing the FG5 in helium gas we can achieve 88% of the effect of placing the entire laser path in vacuum.

Unexpectedly, the helium atmosphere caused the laser to fail, apparently because Brewster's angle changed by enough to misalign the optics. Fortunately we were able to change to a different gravimeter that uses a fiber-optic cable to transmit a beam from an external laser into the interferometer inside the aluminized mylar bag.

We processed the drop data by fitting fourth-order curves to the delay vs. time values from the interferometer. The averaged or "stacked" the residuals from the data with and without the helium atmosphere are shown below. There is a marked reduction in the post-fit residuals at frequencies of about 50 Hz and little or no effect at higher frequencies. We have developed a qualitative explanation of the frequency cutoff in terms of motion of air under compression.

Additional experiments to characterize the effect of the window vibrations on the FG5 residuals are under consideration including measurements of the window vibration using a variety of capacitive, inductive or optical non-contact sensors that are currently available. The actual observed vibration displacement vs. time curves can be fit to the residuals using a variety of cutoff frequencies to help further understand the contribution of the window vibrations to the error spectrum of the FG5 gravimeter.

Research Theme: *Planetary Metabolism*

The sustainability of the biosphere during the current period of rapid changes in the earth system is an issue of prime importance for the environmental sciences. The physical and chemical features of the earth are intimately tied to organisms and the activities required for their sustenance. The health of the biosphere can usefully be considered using the concept of "planetary metabolism", which refers to the complex web of biochemical and ecological processes that occur within the biosphere, and the interaction of these processes with the lithosphere, atmosphere and hydrosphere. Both natural and anthropogenic disturbances drive the structure and dynamics of natural systems, and a thorough understanding of these complex processes is essential for efforts to protect the biosphere from adverse effects due to pollution, destruction of natural landscapes, and alteration of climate. The following are the current areas of our primary focus.

Biogeochemical Cycling

Global networks of trace gas and stable isotope analysis, in combination with global circulation models, are currently being used to discern the global distribution of photosynthetic and respiratory sources and sinks. Inverse modeling approaches are enabling the partitioning of global carbon cycle components into oceanic and terrestrial components to identify more explicit latitudinal and longitudinal coordinate bands for particularly strong source and sink activity.

Biosphere-Atmosphere Interactions

Examples of specific studies include: an investigation of the reactivity of organic molecules in organic aerosols; quantifying carbon fluxes between the forest and the atmosphere; understanding the primary ecological controls over the rate and seasonal pattern of carbon sequestration; and studies on the ecological controls over methane emission from tropical wetland ecosystems that indicate methane emissions from tropical wetlands have probably been overestimated.

Response of Natural Systems to Perturbations

The response of natural systems to perturbations is being studied at scales ranging from the microbial to the global. Examples include: the evolution of metabolic pathways for degradation of pesticides in a soil bacterium that contributes to our knowledge of the ability of microorganisms to adapt to and degrade novel compounds in the environment; studies of regional and global land-use perturbations and their influence on biogeochemical cycles; studies of the factors controlling the deposition of oxidants and how such deposition affects primary productivity and ecosystem water use; and studies of perturbations in the nitrogen cycle of watersheds caused by increases in atmospheric deposition of nitrogen from anthropogenic sources.

Transport and Fate of Chemicals in the Biosphere

Example projects include: investigation of the fate of nitrogen oxide compounds emitted from temperate agricultural soils and tropical soils; studies of the uptake of atmospheric aerosols by various biological surfaces that will contribute to a fundamental understanding of how vegetated surfaces interact with the atmosphere through heterogeneous processes; and development of a new approach for estimating yields of nitrogen from continents to oceans under pre-industrial (background) conditions to be used as a benchmark against which human perturbations of the nitrogen cycle can be judged.

Coupled Inverse Modeling of Methane and Carbon Dioxide and Carbon Monoxide

Project Personnel: S. E. Mikaloff Fletcher, P. P. Tans, and L. M. Bruwhiler

Theme(s): Planetary Metabolism; Advanced Observing and Modeling Systems

Payoff: Improving modeling techniques used to estimate the budgets of trace gases critical to global climate forcing and atmospheric chemistry.

Funding Sources: CIRES (through CIRES Graduate Fellowship), NOAA

Understanding the budgets of methane, carbon dioxide, and carbon monoxide is crucial to predicting climate change and managing earth's carbon reservoirs. At present many of the sources and sinks of these trace gasses cannot be quantified with sufficient accuracy, due in part to the large spatial and temporal variability of the sources.

Inverse modeling is a class of techniques that can be employed to estimate trace gas budgets by using observations of atmospheric trace gases and a global transport or general circulation model to estimate sources and sinks. Because inversions are based directly on regular observations of trace gases, they may provide unique insight into spatial and inter-annual variability. While inverse models are potentially powerful methods to recover sources and sinks on a global scale, insufficient sampling and sampling biases significantly limit their accuracy. By using observed relationships between trace gases to further constrain the problem, it may be possible to improve the accuracy of source estimates.

In order to investigate the advantages of using additional constraints, the TM3 three-dimensional transport model was used. The methane and carbon dioxide measurements used are from a cooperative international effort, the Cooperative Air Sampling Network, lead by the Climate Monitoring Diagnostics Laboratory (CMDL) at the National Oceanic and Atmospheric Administration (NOAA).

Multiple emission ratio constraints were tested for their ability to improve inverse estimates. All constraints used significantly improved the error estimates for the inversion results. In some inversion scenarios, the coupled inversion was able to resolve the seasonal cycle where the uncoupled inversion was not. For example, in figure1, the methane wetland source was coupled to the carbon dioxide terrestrial biosphere source using measured relationships1 between emissions of the two gases from wetlands. The coupled inversion captures the general features of the seasonal cycle expected from independent estimates[2] while; the uncoupled inversion does not resolve a seasonal cycle. Coupling between the biomass burning source of carbon monoxide and methane through measured emission ratios did not significantly improve estimates of either trace gas. Early experiments with carbon isotopes suggest that $^{13}CH_4$ may be a useful constraint for the methane budget.

1 Whiting, G. J. and J. P. Chanton, Primary production control of methane emission from wetlands, *Nature,* 364, 794- 795, 1993.

[2]Granier, C., personal communication, 1999

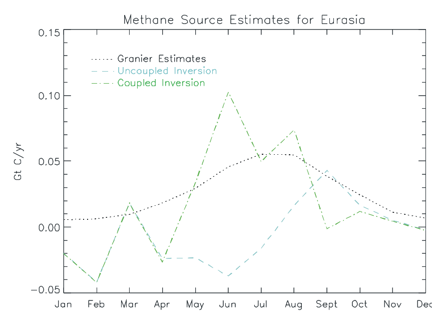


Figure 1. Three estimates of the seasonal cycle of methane flux from wetlands and rice paddies: eight-year average of the uncoupled inversion, green; eight-year average of the coupled inversion, blue; independent estimate2, black.

Optical and Chemical Properties of Organic Atmospheric Aerosols

Project Personnel: G. B. Ellison, A. F. Tuck, V. Vaida, D. J. Donaldson, C. M. Dobson, T. Eliason,

Themes: Planetary Metabolism, Climate System Variability

Payoff: Proposed a chemical model for organic atmospheric aerosols with implications to the current and prebiotic atmosphere.

Funding Sources: NSF, Camille and Henry Dreyfus Foundation, NOAA, CIRES

The atmosphere is a complex, dynamic system whose temperature, climate and chemistry are driven by light from the Sun. Traditionally it was thought that only gas phase processes, bimolecular or three body reactions were important in maintaining the Earth thermal and chemical balance. More recently, it has been established that heterogeneous processes, including those, which involve clouds and aerosols, play a very important part. Atmospheric aerosols have been found to contain organic materials in significant amounts (10 to 50 % by weight). Organic chemicals are common constituents of aerosol particles and many of them are surface active. For example, fatty acids derived from the decomposition of lipids of natural origin are found at the surface of the ocean, in both saturated and unsaturated form. Ellison, Vaida, and Tuck have proposed that these fatty acids coat aqueous aerosol particles and influence their nucleation and radiative properties, thus affecting the atmosphere's energy budget. The proposed model portrays a reverse micelle structure for nascent organic aerosols with an aqueous core and an organic amphiphilic coating, and outlines the chemical processing by atmospheric radicals.

The conceptual model for organic atmospheric aerosols suggested experiments on the optical and chemical properties of organic films on aqueous solutions prepared in Langmuir-Blodgett trough studies as well as on actual aerosols. These experiments are underway and involve interdisciplinary collaborations with colleagues at NOAA (A. F. Tuck, D. Cziczo) and CIRES (S. Copley). In addition, the validity of these ideas is tested using field measurements with studies designed to probe the composition and structure of atmospheric aerosols. These studies are performed in collaboration with Dr. Heikki Tervahattu, Helsinki University.

Regional NPP and Carbon Stocks in Southwestern USA Rangelands: Land-Use Impacts on the Grassland-Woodland Balance

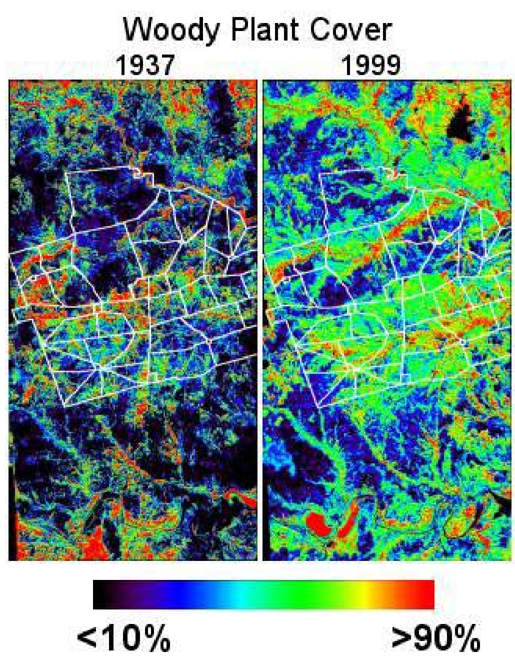
Project Personnel: C.A. Wessman, G.P. Asner, C.A. Bateson, S. R. Archer (Texas A&M)

Theme(s): Planetary Metabolism; Advanced Observing and Modeling Systems

Payoff: Increased understanding of ecological & biogeochemical trajectories with land-use change.

Funding Source: NASA

Dryland ecosystems store 30% of global soil organic carbon (C), cover half the terrestrial surface, support 20% of the human population, and produce 70% of the world's livestock. The historical land cover of these geographically extensive regions was primarily grassland and savanna. However, exponential growth of the human population accompanied by fire suppression and intensification of land uses over the past century has lead to dramatic and widespread increases in tree and shrub cover in these dryland ecosystems. These vegetation changes can alter soil C storage and dynamics by changing: (i) the quantity and quality of above- and belowground organic matter inputs, (ii) the depth at which organic C is stored in soil, and (iii) environmental factors (soil moisture, temperature) that regulate rates of soil organic matter decomposition. The biogeochemical, hydrologic, and climatic consequences of this geographically extensive conversion from grass to woody plant domination are of great concern, but remain largely unknown. Moreover, we lack comprehensive information on the historic or modern rate, areal extent and pattern of woody plant expansion in the world's drylands. As a result, it is difficult to objectively or quantitatively assess implications for regional and global C and N cycling. In confronting these challenges, our team has developed novel and viable approaches for coupling field data, isotope biogeochemistry, remote sensing, and modeling to quantify the impact of woody plant encroachment on aboveground biomass and C and N pools and primary production at spatially complex local and regional scales. We are currently expanding our Texas-based work to assess land-use impacts on NPP and C-storage in rangeland ecosystems throughout the Southwest.



Studies of Enzymes That Have Been Recruited to Serve New Functions in the Degradation of a Xenobiotic Compound

Project Personnel: S. Copley, P. Kiefer, Jr., K. Anandarajah, M.-H. Dai

Theme(s): Planetary Metabolism

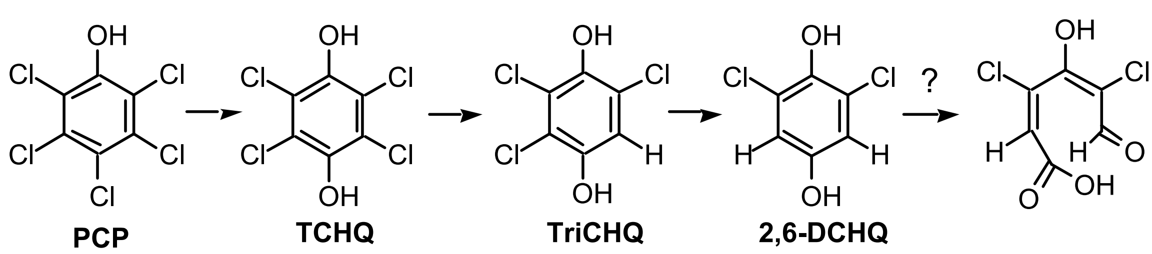
Payoff: Improved understanding of how microorganisms evolve pathways for degradation of xenobiotic compounds

Funding Sources: NSF, ARO

Many chemicals used in manufacturing, agriculture, and even households are xenobiotic (foreign to life). Since these chemicals have been present in the environment for only a short time, they pose special environmental problems. Many are not biodegradable because microorganisms lack the enzymes necessary to catalyze their degradation. We are studying the evolution of a new metabolic pathway in *Sphingomonas chlorophenolica*, a soil bacterium that can mineralize pentachlorophenol (PCP). PCP was first introduced as a pesticide in 1936. *S. chlorophenolica* has assembled a new metabolic pathway for degradation of this xenobiotic compound by patching together enzymes recruited from two pre-existing pathways. Our studies address issues such as the origin of enzymes that are serving new functions, how well these enzymes are performing in their new roles, and how the regulation of the genes encoding these enzymes must change in order to properly regulate the newly assembled pathway.

PCP hydroxylase catalyzes the first step in the degradation of PCP. This enzyme is an outstandingly poor catalyst. It appears to catalyze the rate-limiting step for degradation of PCP. This enzyme was most likely recruited from an enzyme that originally hydroxylated a naturally occurring phenol, but it has clearly not yet evolved to be an effective catalyst for hydroxylation of PCP. We are attempting to identify the steps that are responsible for the poor catalytic activity and to use *in vitro* evolution techniques to generate an improved enzyme. Thus far, we have achieved a seven-fold increase in the catalytic activity of the enzyme. Attempts to further improve the enzyme and to analyze the reasons for the improved performance are underway.

Tetrachlorohydroquinone (TCHQ) dehalogenase catalyzes the second and third reactions in the pathway. We have recently discovered that TCHQ dehalogenase has likely evolved from an enzyme that catalyzes glutathione-dependent isomerization of a double bond, a strikingly different transformation. TCHQ dehalogenase catalyzes both reactions at the same active site. Our challenge is to understand why the enzyme can catalyze both reactions and why an active site suitable for catalysis of the isomerization reaction provided a suitable starting place for evolution of a reductive dehalogenase. We suspect that there are underlying similarities in the mechanisms of these two seemingly very different reactions such that key catalytic residues in the active site can facilitate both reactions. We have recently completed studies that define the mechanism of the dehalogenation reaction, and have proposed a model for the mechanism of the isomerization reaction that will be investigated in the coming year.



Multiscale Hydrologic Analyses on River Networks

Personnel: V. K. Gupta (PI), P. Furey (RA), S. Veitzer (RA), R. Mantilla (GRA)

Theme(s): Planetary Metabolism; Regional Processes

Payoff: Developing physical-mathematical foundations of hydrologic variability across multiple scales of river basins, and their applications to hydrologic predictions

Funding Sources: NASA, NSF

"Naturalized" streamflows at locations with substantial human modification of the land hydrology are often needed. Streamflow records often have missing values that need to be imputed from other sources. During extreme conditions, gage streamflows tend to have large errors, and auxiliary estimates are desirable. Collectively, these issues define the ungauged and poorly-gauged flow estimation problem. This major global hydrologic problem arises in the context of diagnosing human induced change in water availability from natural and/or climate induced changes. It has remained a seminal unsolved problem in hydrology, and the current modeling approaches are unsuitable to tackle it.

Our research group has led this research effort nationally and internationally. Recent advances suggest that there are three broad components to this problem. The first is to develop a methodology for partitioning space-time rainfall time series (or snowmelt time series) into overland flow, baseflow and evapotranspiration (ET) over long time scales. This issue can be approached through a physically-based filter for separating base flow time series from streamflows given rainfall and ET fields. Furey and Gupta (2000, 2001) give the first set of results. This filter is being tested using a hillside runoff generation model, rainfall, ET and gauged streamflows, without involving model calibration. The second issue is to develop and diagnose a theoretical framework to transport water on a channel network, which explicitly incorporates the spatial and the hydraulic-geometric variability of the network and conserves mass (Veitzer and Gupta, 2001; Manmade et. al., 2001). The third issue is to diagnose the statistical structure of spatial variability across multiple scales using scale-invariant flood statistics on a network. A new physical-statistical theory is being developed and tested for this purpose.

Research Theme: *Advanced Observing and Modeling Systems*

Several research initiatives and ongoing projects in CIRES are currently using advanced observing and modeling techniques. It is our aim to make use of this synergism and to promote cross-discipline discussions and collaborations in this field.

Atmospheric Chemistry

Research is focusing on improving observations of important chemical species, aerosols and their precursors, with emphasis on remote measurements, miniaturized instruments for deployment on kites or small aircraft, fast response observations, and high sensitivity. Specifically, fast response methods are being developed to enable high-resolution observations of the temporal and spatial variability of aerosols and fine particles. New absorption techniques for characterizing the column density of chemically active and/or radiatively important compounds that influence regional air quality and climate, especially from airborne platforms, are also being pursued.

Atmosphere and Ocean Physical Parameters

The goal of this element is to investigate the use of new remote sensing methods for observing atmospheric winds and water vapor, cloud microphysical and radiative properties, and ocean surface characteristics. An important focus of this element will be the development of techniques and instrumentation suitable for mounting on ships, aircraft, remotely piloted vehicles, and kites and balloons. Another area of concentration will be the investigating the benefits of combining measurements from different sensors and numerical models to produce estimates of parameters not well measured with any single technique.

Cryosphere

The goal of this element is to improve measurements and models of important cryospheric parameters. A main focus will be assessment of data from a new generation of satellite sensors and its impact on measurements of snow cover, snow albedo, ice sheet mapping, and energy balance modeling. Modeling efforts will be conducted in parallel with observational research to parameterize snow structure, model surface energy balance based on atmospheric and cryospheric interactions, and to investigate ocean-ice-atmosphere and land-atmosphere processes at high latitudes.

Data Centers and Data Management

CIRES is connected with several groups involved in data management that include NSIDC, CDC, NGDC and CSES (CIRES Center for the Study of Earth from Space). Good data management is essential to ensuring the preservation of important in-situ and satellite observations and continuing long data time series. This is crucial for the validation and parameterization of models, data assimilation efforts, and the understanding of regional-scale processes.

Ecosystem and Environmental Modeling

The definition of objects (ecosystems) that we characterize must also be understood as changing and evolving, both in response to natural change and human influence/management. Develop new and effective methods to characterize and model managed ecosystems, prioritize management needs, and prescribe appropriate actions.

Remote Sensing of Terrestrial Properties

A goal of the research under this element is to investigate the use of hyperspectral imaging as a standard technique for remote observation of the earth. Another goal to be pursued is the application of data from the gravity mapping satellite GRACE, scheduled for launch in 2001, to estimate parameters that can be identified through redistribution of mass within the earth.

Research Theme: *Advanced Observing and Modeling Systems*

(Continued)

Non-linear Systems

The primary goal of this research element is to develop nonlinear Earth system models and simulations to address fundamental questions that can be understood by no other means. An important aspect of this research is cataloging and understanding the nature and configurations of space-time patterns of earth system phenomena, and examining whether these are scale-dependent or scale-invariant in space and time. This includes identification of certain characteristic patterns that may indicate smaller events precursory to more disastrous, great events such as destructive earthquakes, hurricanes, ENSO's, ozone hole, extinction events, and asteroid impacts. Other goals of this element are aimed at developing and testing potential forecast algorithms, based primarily upon the use of space-time patterns in the earth systems of interest, and understanding the physical conditions that allow space-time coarse-graining of sub-grid scale processes in simulations.

Space Weather

One goal of this element is to investigate the coupling between the various regions of the space environment, such as solar wind-magnetosphere, magnetosphere-ionosphere, and lower atmosphere-upper atmosphere. A second goal will be to develop Kalman filter and adjoint modeling data assimilation techniques, in order to parallel recent advances in tropospheric weather forecasting for optimal combination of models and data in strongly forced systems. This activity will include investigation of the infrastructure to ingest data from new satellite constellations such as COSMIC (Taiwan and US) and NASA's Living with a Star (LWS) mission.

Database on Chemical Composition of Aerosols Established

CIRES Investigators: Thomson, Aikin

Theme(s): Advanced Observing and Modeling Systems

Payoff: Making research data widely available to research colleagues and the public

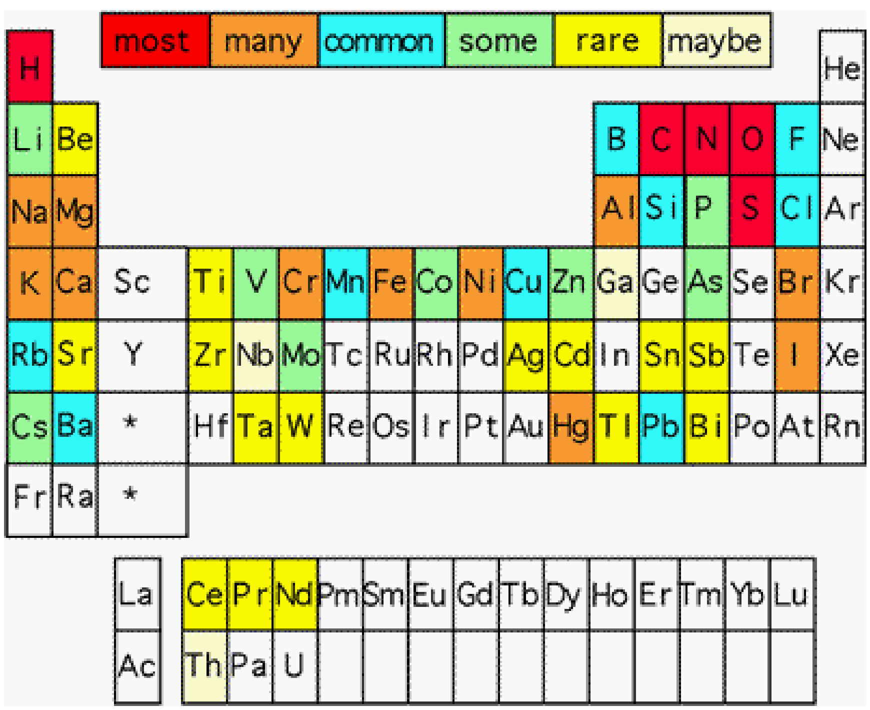
Funding Sources: NOAA

Knowledge of fine particle properties and sources are needed to evaluate and manage a wide variety of air quality concerns. These include the concentrations and physical and chemical properties of particles that effect human health, atmospheric visibility, acid deposition, and climate change. To undertake credible air quality management, a full understanding of the composition and distribution of particulate matter in the atmosphere and their effects on health and the environment is required. This places rigorous demands on the measurement techniques and the systems that apply them.

The CIRES and NOAA scientists at the Aeronomy Lab have launched a new page on its website. The page provides on-line access to the very rich database from the Aeronomy Lab's Particle Analysis by Laser Mass Spectrometry (PALMS) instrument. This unique dataset gives a full, detailed mass spectrum for each of thousands of individual particles that have been sampled and analyzed in real time.

The user can view data from both ground-based measurements with the instrument (dating back to 1993), as well as the airborne measurements made using the NASA WB-57 aircraft during the last 3 years. The database is searchable and interactive. The spectra of over 50,000 individual particles are available in the database.

The goal of the web page is to foster more collaboration and data analysis from this rich and unique database. It is easily accessible directly off of the Aeronomy Lab home page, http://www.al.noaa.gov, under the "datasets" section.



The periodic table of elements observed in aerosol particles by the PALMS instrument at altitudes above 5 km.

Virtual Ocean Data Hub, Western Water Assessment On-line

Project Personnel: T. Habermann, J. Cartwright, M. Ohrenschall, C. Anderson

Theme(s): Advanced Observing and Modeling Systems; Regional Processes

Payoff: Improved access to distributed science data

Funding Sources: National Ocean Partnership Program, Federal Geographic Data Committee

Recent developments in relational databases and geographic information systems are greatly simplifying the process of integrating and sharing data. This group at NGDC is working to apply these new technologies in several partnerships: The Virtual Ocean Data Hub and the Western Water Assessment On-Line.

The Virtual Ocean Data Hub is a partnership of 50 academic, government, and private sector groups interested in Oceanographic Data. The goal is to increase the amount of oceanographic data available on the World Wide Web. CIRES has partnered with the Environmental Science Research Institute (ESRI) to develop mechanisms for accessing data in traditional science formats using geographic information systems.

The Web Mapping Standards developed by the Federal Geographic Data Committee (FGDC) provide a framework for creating maps on the web from distributed data sources. The goal of this project is to help the FGDC test and develop those standards using data from the Western Water Assessment. This will be accomplished using commercial tools to provide connections to data at CDC and at CIRES. Data from both locations will be displayed on a web client using the ESRI Internet Map Server and open source viewers created using the Web Mapping Testbed Standards.

Polar Applications of Multiangular Remote Sensing

Project Personnel: Anne Nolin, Florence Fetterer, Ted Scambos, and Julienne Stroeve

Theme: Advanced Observing and Modeling Systems

Payoff: Improved mapping and characterization of ice sheets and sea ice.

Funding Sources: NASA

An innovative approach to satellite mapping of snow and ice has recently been developed using data from a new sensor onboard NASA's Terra satellite. The Multiangle Imaging SpectroRadiometer (MISR) has nine cameras, each pointing at a different angle along its satellite trajectory. These simultaneous multiangular views allow one to record the angular "signature" of different types of snow and ice. Satellite mapping of conditions in the polar regions is an important part of detecting climate change. In our recent work, we have learned that we can distinguish between sea ice types on the basis of their angular signatures. Over the Greenland ice sheet, we see good correspondence between the different zones of snow accumulation and the relationship between forward and backscattering as detected by MISR. In Antarctica, blue ice areas, which are known to represent areas of mass loss on the ice sheet, are easily detected using multiangular data. These unusual ablation surfaces are smooth and, unlike nearby crevassed ice, are strongly forward scattering. The figure below shows both a true color composite image and an angular color composite image. In this latter image, blue ice areas are easily distinguished from glacier crevasses. These case studies demonstrate that MISR data can make an innovative and important contribution to remote sensing of snow and ice.

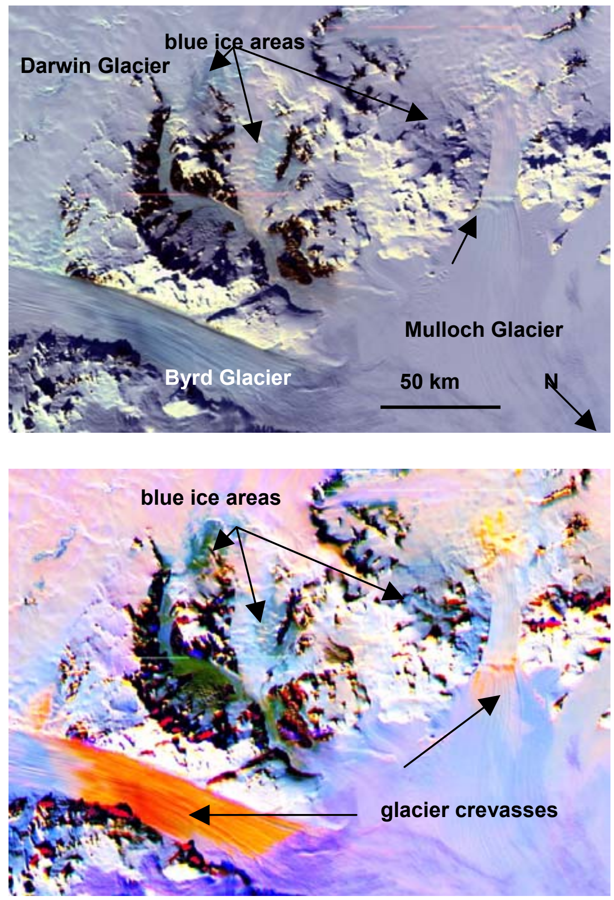


Figure 2. The top image is a true color composite image of an area in East Antarctica with both glaciers and blue ice areas. The Ross Ice Shelf is in the lower right. Dark areas are exposed rock. The lower image is an angular false color composite image (red=backward, green=nadir, blue=forward). Smooth areas such as the blue ice areas show up in tones of blue while rough-textured surfaces such as the glacier crevasses are orange-red. Clouds (in the lower part of the image) are purple.

Variability and Forcing of Climatic Parameters on the Greenland Ice Sheet

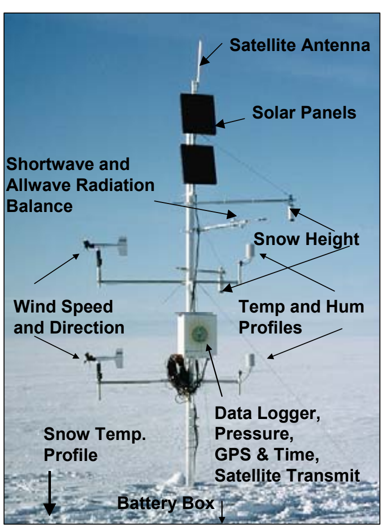
Project Personnel: K. Steffen, J. Box

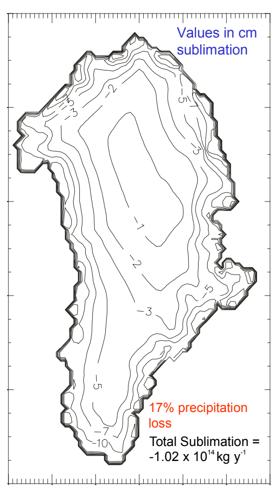
Theme(s): Advanced Observing and Modeling Systems

Payoff: Improved understanding of climate and climatic feedback on the Greenland ice sheet.

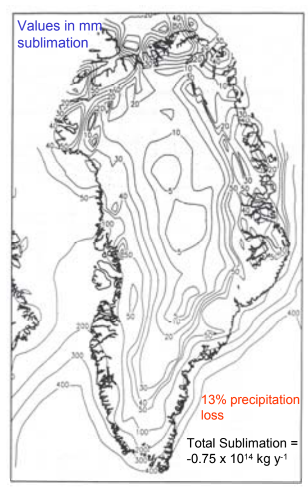
Funding Source: NASA Cryospheric Program

The Greenland climate network currently has 18 automatic weather stations (AWS) distributed in most climate regions of the ice sheet. The present network captures well the regional climates and their differences in the accumulation region of the ice sheet. An annual mean latitudinal temperature gradient of -0.78ºC / 1º latitude was derived from the AWS data for the western slope of the ice sheet, and an annual mean latitudinal temperature gradient of -0.82ºC / 1º latitude was derived for the eastern slope. The mean annual lapse rate along the surface slope is 0.71ºC / 100 m, with monthly mean lapse rates varying between 0.4ºC / 100 m in summer and 1.0ºC / 100 m in winter. The annual range of monthly mean temperatures is between 23.5ºC and 30.3ºC for the western slope of the ice sheet, with increasing ranges from south to north and with increase in elevation. The annual mean air temperature was found to be 2ºC warmer for the central part of Greenland for the time period 1995–1999, as compared to the standard decade 1951–1960. This annual mean temperature change decreased to approximately 1ºC for the elevation 1000–2000 m, whereas at lower elevations, no AWS data are available with sufficient spatial and temporal coverage to verify any temperature trend. Firn temperatures (10-m depth) at high-elevation sites were found to be colder than the mean annual air temperature of the preceding year for the central part and northern Greenland by as much as 2.5ºC. In the percolation zone and at the equilibrium line altitude the firn and ice temperatures at 10 m were consistently warmer than the annual mean air temperature because of percolation of meltwater and the isolation effect of the snow cover. The wind speed and direction are affected by the katabatic outflow of the cold air along the slope of the ice sheet, whereas at higher elevations the large-scale synoptic condition is the dominant factor that governs the wind field. The surface height change at high elevations (accumulation minus sublimation) can be approximated with a linear model over an annual cycle using AWS data, whereas in the ablation region and along the equilibrium line altitude the surface height change shows a strong annual cycle.





Saturation method using one levels (PhD thesis Jason Box)



GCM computed values by Ohmura et al, (1999).

Evaluation of Proposed Doppler Lidar for Satellite-Based Global Wind Measurements

Project personnel: B.J. Rye (CIRES), A. Brewer, G. Feingold, R.M. Hardesty (NOAA)

Theme(s): Advanced Observing and Modeling Systems

Payoff: Deployment of system providing wind data for use in weather forecasting commercially.

Funding Source: NOAA

This program is part of a larger effort within NOAA supported by funds earmarked by Congress. Its purpose is to support development of a satellite system for making measurements of wind profiles, which will improve the accuracy of weather forecasts. A private company is funded by NOAA to build the prototype of the Doppler lidar, and NOAA research laboratories are required to evaluate the instrument, its likely performance, and the quality of the data it would provide. Two laboratories under NOAA's OAR are involved in the evaluation program. ETL is charged with examining the performance of the prototype lidar and with providing FSL with data of the type that the satellite lidar is expected to generate, based in part on the perceived performance of the lidar. This data will be entered into FSL numerical Observing System Simulation Experiments (OSSEs) to help determine whether the improvement in weather forecasts would justify the expense of a satellite system. The FSL modeling is to be linked with modeling undertaken by NCEPS under the overall supervision of NESDIS.

The prototype lidar, termed Groundwinds, was installed with NOAA support at the University of New Hampshire. It exploits molecular scattering and, unlike conventional aerosol backscatter systems, can therefore make measurements at all altitudes of interest at all times provided the target volume is not obscured by cloud. The lidar intercomparison experiment incorporated two other Doppler lidars, a new instrument developed at NASA Goddard Space Flight Center, which also uses molecular scattering, and the mini-MOPA lidar operated by ETL over several years, which has proved capable of measuring winds using aerosol backscatter and clouds with high accuracy. In addition, an ETL wind profiler (radar) provided winds to 4-5 km altitude, and balloons were launched at frequent intervals. The Groundwinds lidar initially exhibited periods when its performance was unreliable, which was not entirely unexpected, as it had only recently been installed. Once the worst of these problems had been sorted out, results from the three lidars agreed qualitatively and were consistent with profiler and balloon measurements. Closer examination of the results led to the conclusion that, while Groundwinds performed as expected given the signal level it was detecting, this signal level was far lower than it should have been based on the instrument parameters.

The satellite model (Windlab) is software that reproduces the measurements a satellite borne Doppler lidar would be expected to generate. FSL are concerned with short-range regional forecasts, which requires modeling on smaller distance scales than has been previously attempted in this application. Windlab is in an advanced state of readiness and it is expected that initial runs of the FSL OSSE will take place shortly.

High-Resolution Observations in the Boundary Layer Using Range Imaging

Project Personnel: P. B. Chilson, Andreas Muschinski, and R. G. Strauch

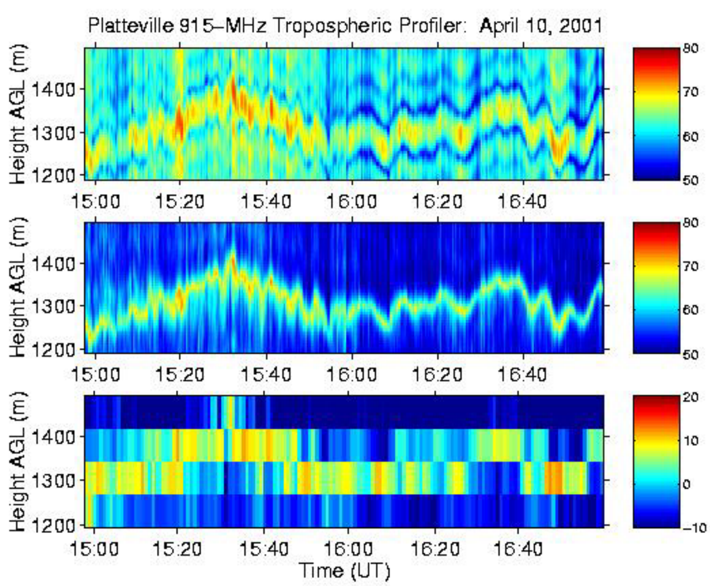
Theme(s): Advanced Observing and Modeling Systems

Payoff: Improved range resolution for wind profilers

Funding Source: NOAA

Range imaging (RIM) has been recently implemented on a UHF profiler at the Platteville Atmospheric Observatory. RIM provides a means of improving vertical resolution through frequency diversity [Palmer et al., Radio Sci., 34, 1485, 1999]. In this technique, several closely spaced carrier frequencies are transmitted and received.

On April 10, 2001 a successful RIM experiment was conducted. During the experiment, the radar was operated alternately in two modes. In one mode, the nominal range resolution of the radar was 300 m and 4 frequencies were transmitted and received. RIM was then used to probe inside of each nominal range gate. In the second mode, standard radar observations with a range resolution of 75 m were made. These were used for comparison with the RIM data. Some results from the experiment are shown in the figure below. The upper panel shows RIM results processed using a Fourier method, which is known to produce "ghost images". The middle panel shows results from an adaptive method of calculating RIM results. The adaptive method suppresses the ghost images and improves resolution. Finally, the lower panel shows the results from the conventional 75-m resolution experiment over four consecutive range gates. Note that the RIM results correspond to a single range gate of 300 m, which matches the range of the four 75-m resolution range gates. The adaptive RIM technique has done a good job in capturing the dynamics and thickness of the layer. RIM mode observations would be ideal, as an example, for monitoring the height and thickness of the top of the boundary layer.



Sound Propagation in a Turbulent Atmosphere Near the Ground

Project Personnel: V. E. Ostashev, S. Clifford, R. Lataitis.

Theme(s): Advanced Observing and Modeling Systems

Payoff: Development of a new theory of sound propagation in a turbulent atmosphere near the ground and its experimental verification.

Funding Sources: NOAA, ARO

For many problems of atmospheric acoustics, a sound field is the sum of the direct wave from the source to the receiver and that reflected from the ground. The interference between these waves results in the interference maxima and minima of the sound pressure. Quite often, the source and receiver are close to the ground while the horizontal distance between them is in the range from several tens to several hundred meters. In this case, the amplitude of the sound pressure can be very small at interference minima in the absence of atmospheric turbulence. But turbulence is always present in the atmosphere. It results in random fluctuations in phase and amplitude of the direct and ground-reflected waves, and partial or complete destruction of the coherence between these waves. This destruction can cause an increase of the mean squared sound pressure by tens of dB.

We developed a new theory of the interference of direct and ground reflected waves in a turbulent atmosphere, which is based on the parabolic equation for sound waves and the Markov approximation for temperature and wind velocity fluctuations. This theory generalizes and revises previous theories of the interference of direct and ground reflected waves in a turbulent atmosphere. Predictions of the developed theory are in good agreement with experimental data obtained in a large anechoic chamber in Ecole Centrale de Lyon, France. The theory is important for many problems in atmospheric acoustics: studies of noise pollution near airports, highways, and factories; source detection and recognition; acoustic tomography of the atmosphere.

High-Resolution Measurements of Turbulent Structure in the Atmospheric Boundary Layer Using the CIRES Tethered Lifting System (TLS)

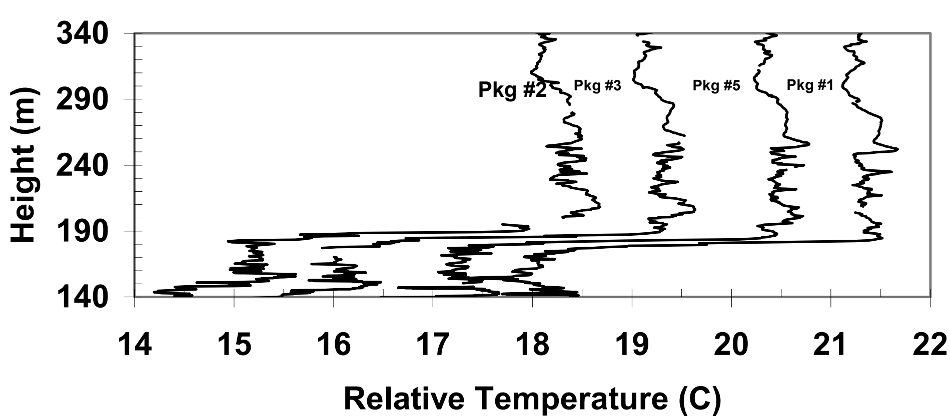
Project Personnel: B. Balsley, M. Jensen, R. Frehlich, A. Muschinski

Theme: Advanced Observing and Modeling Systems

Payoff: A greatly improved capability for resolving turbulence and associated detailed structures throughout the first few km of the atmosphere

Funding Sources: NSF, NOAA, Army Research Office

The University of Colorado's Cooperative Institute for Research in Environmental Sciences (CIRES) has initiated a series of vertical profiling measurements in and above the atmospheric boundary layer (ABL) using the CIRES TLS (Tethered Lifting System). The TLS consists of either a kite or an aerodynamic balloon capable of lofting up to six sensitive "turbulence" sensors separated vertically by pre-selected spacings to altitudes up to a few km. Initial measurements were made during the CASES-99 Campaign in central Kansas in the fall of 1999. The bandwidth of these probes is such that they can provide 0.4 cm resolution of vertical structure of ABL turbulence and related quantities. Examples of vertical temperature structure shown below were gathered during a nighttime period during CASES-99 when an extremely steep positive temperature gradient was developing in the height range 180-190 m. The magnitude of this gradient measured by all four turbulence probes separated vertically by 6 meters was 28°C m^{-1}. Although gradients of this magnitude have never before been documented, it is clear that they are probably commonplace under some circumstances. An additional conclusion is that the constancy of this feature over the 45 seconds required for all four probes to pass through the region (see figure), and taking into account the fact that such a gradient would be advected by the wind, indicates that the gradient extends horizontally for at least 500 m. Finally, a correspondingly sharp thirty-fold decrease in the magnitude of turbulence structure was observed as the sensors traveled upward through this temperature gradient. Since turbulence is also advected by the wind, this steep gradient in turbulence also clearly extended horizontally by more than 500m.



Package #2 temperature is correct, while the other profiles (#3, #5, #1) have been offset consecutively by 1.5 °C for viewing facility. Probe separation was 6 m and probe sequence was #2, #3, #5, and then #1, as they traveled upward through the region.

First-Principle Theory of the Doppler Velocity Measured with Radar Wind Profilers

Project Personnel: Andreas Muschinski and Valeryan I. Tatarskii

Theme(s): Advanced Observing and Modeling Systems

Payoff: First-principle understanding of the key working hypothesis of wind profiling

Funding Sources: NOAA, Army Research Office (ARO)

For more than 25 years, radar wind profilers have been used to remotely measure wind velocities in the troposphere, stratosphere, and mesosphere. Since the early eighties, radar wind profilers have also been in use in the operational or semi-operational arenas.

It is easy to demonstrate that the Doppler velocity (the properly scaled Doppler shift) is identical to the radial target velocity if the target is a point scatterer in the far field and if effects of a finite observation volume play no role. If there are many point scatterers, the cross section and velocity of which are statistically independent, then the ensemble-averaged Doppler velocity is equal to the ensemble-averaged radial target velocity.

Muschinski (1998: The first moments of the variance- and cross-spectra of standard and interferometric clear-air, Doppler-radar signals. *NCAR Techn. Note* 441+STR, 102 pp., NCAR, Boulder, Colorado) derived, on the basis of first-principle wave propagation theory, an equation for the Doppler velocity in the case of radio-wave, volume scatter from turbulent refractive-index perturbations in the clear air. He found that even in the ideal case of stationary and homogeneous turbulence, the ensemble-averaged Doppler velocity is the sum of the ensemble-averaged radial wind velocity and a second term that is proportional to the Bragg wave vector component of the spatial quadrature spectrum of the refractive-index flux in the radial direction. That is, in the case of a finite vertical refractive flux (like in the daytime boundary layer) there may be a non-zero ensemble-averaged Doppler velocity even if the ensemble-averaged radial wind is zero. This is in contrast to the key working hypothesis of wind profiling, namely that in the case of homogeneous and stationary turbulence, the Doppler velocity is an unbiased estimator of the radial velocity.

In a recent paper, Tatarskii and Muschinski (2001) rederived Muschinski's (1998) result and investigated this second term, which they termed "correlation velocity," more quantitatively. A major part of the study by Tatarskii and Muschinski (2001) is a first-principle analysis of the properties of the spatial cross spectrum of refractive-index and wind perturbations. The correlation velocity can be directly measured with bistatic or multistatic configurations, which would allow one to scan in wave-number space.

Advanced Theoretical Model of VHF Aspect Sensitivity

Project Personnel: Andreas Muschinski

Theme(s): Advanced Observing and Modeling Systems

Payoff: First-principle understanding of an important phenomenon in atmospheric remote sensing

Funding Source: NOAA, Army Research Office (ARO)

The classical 1974 paper by Woodman and Guilleen on experiments using the Jicamarca (Peru) VHF radar is widely considered the birth of the wind-profiler technology. In contrast to clear-air radar observations made at UHF frequencies (typically at 400 MHz and higher frequencies), VHF (typically at 50 MHz) echoes from the clear air often show a strong maximum in the echo intensity if the beam is pointed vertical or close to vertical. Since the two classical papers by Röttger and Liu and by Gage and Green in 1978, the VHF aspect sensitivity has been the topic of hundreds of observational and theoretical papers.

There is general agreement that the aspect-sensitive reflectivity maximum is caused by scatter/reflection from single or multiple, horizontally extended interfaces (or "sheets") in the refractive-index field. The associated scattering mechanisms have been termed "Fresnel reflection," "Fresnel scatter," "diffuse reflection," or "specular reflection," depending on whether there are one or multiple interfaces in the scattering volume, and depending on whether these interfaces are rough or smooth.

A major step forward on the theoretical side was done by Doviak and Zrnic (*Radio Sci*., **19**, 325ff., 1984), who allowed the spatial refractive-index spectrum to be anisotropic and retained the quadratic term in the Taylor expansion of the phase term. This term is ignored in the classical theory of scatter from the turbulent clear air but must not be neglected in the case of specular or quasi-specular reflection at VHF frequencies. Woodman and Chu (*Radio Sci.*, **24**, 113ff.,. 1989) speculated on the physical nature of these interfaces. Their model relied on the assumption that elevated turbulent layers are confined between two interfaces. The existence of these turbulent layers confined between sharp interfaces in the atmosphere has meanwhile been established on the basis of high-resolution *in situ* measurements (Muschinski and Wode, *J. Atmos. Sci*., **55**, 2893ff., 1998; Muschinski et al., *Boundary-Layer Meteorol*., 98, 219ff., 2001).

In a new study, Muschinski (2001) has extended the theory by Doviak and Zrnic (1984) such that the Woodman and Chu (1989) model, which provides a physical connection between the intensity of Bragg scatter and (quasi-) specular reflection (which the Doviak and Zrnic model does not), is quantitatively incorporated. The new model explains quantitatively why there is typically aspect sensitivity at 50 MHz but no aspect sensitivity at 400 MHz and higher frequencies. An essential component of the new model is the two-dimensional structure function of the interface elevation; the local vertical refractive-index profile is modeled by a Gaussian error function.

Implementation of Range Imaging on the Platteville 915-MHz Tropospheric Profiler

Project Personnel: P. B. Chilson and R. G. Strauch

Theme(s): Advanced Observing and Modeling Systems

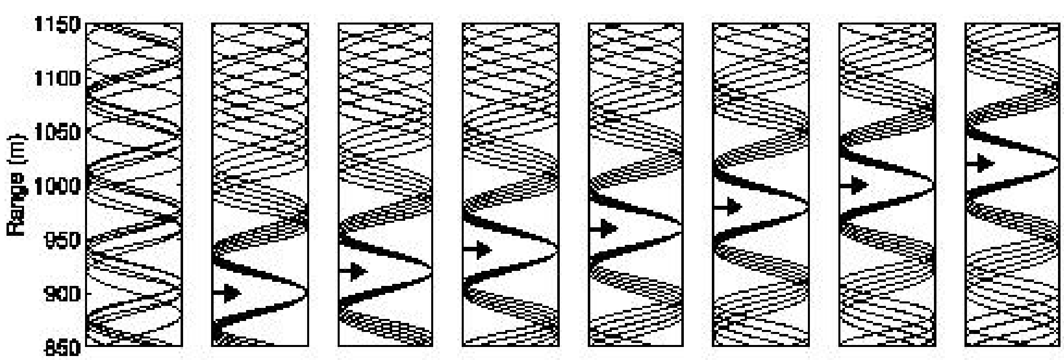
Payoff: Improved range resolution for wind profilers

Funding Source: NOAA

There are a host of phenomena and parameters associated with the atmospheric boundary layer (ABL) and lower free atmosphere that manifest themselves within narrow, well-confined height intervals. Often, measurements of these phenomena are critical to our understanding of the stability and evolution of the ABL, which in turn impacts on weather forecast models, the vertical exchange of mass and momentum, and the generation of turbulence. Examples of these phenomena and parameters are the height and thickness of the entrainment zone, internal gravity waves in stably stratified flows, and Kelvin-Helmholtz instabilites.

Unfortunately, wind profilers must operate within stringent frequency management constraints, which limit their range resolution. Therefore, range imaging (RIM) has been developed as a means of improving vertical resolution through frequency diversity [Palmer et al., Radio Sci., 34, 1485, 1999]. In this technique, several closely spaced carrier frequencies are transmitted and received, and a constrained optimization method is used to generate high-resolution maps of the reflectivity field along the vertical extent. Basically, a weighting is applied to the received signals at the different frequencies in order to create constructive interference between the different signals at a particular range within a nominal range gate. This concept is illustrated in the figure below. The left-most panel depicts the different signals without any attempt of creating constructive interference. The next panels in the figure show how the signals can be “steered” to a particular range denoted by the thick arrow. If vertical structuring in the refractivity field exits within the radar sampling volume, for example from a collection of dominating scattering layers, then RIM can be used to resolve these features.

RIM has been recently implemented on the Platteville 915-MHz tropospheric profiler located at the Platteville Atmospheric Observatory. On April 10, 2001 a successful RIM experiment was conducted.



Impact of Wind Profiler Observations on the NCEP/NCAR Reanalysis over the Tropical Pacific

Project Personnel: R. Schafer, S. K. Avery, K. S. Gage

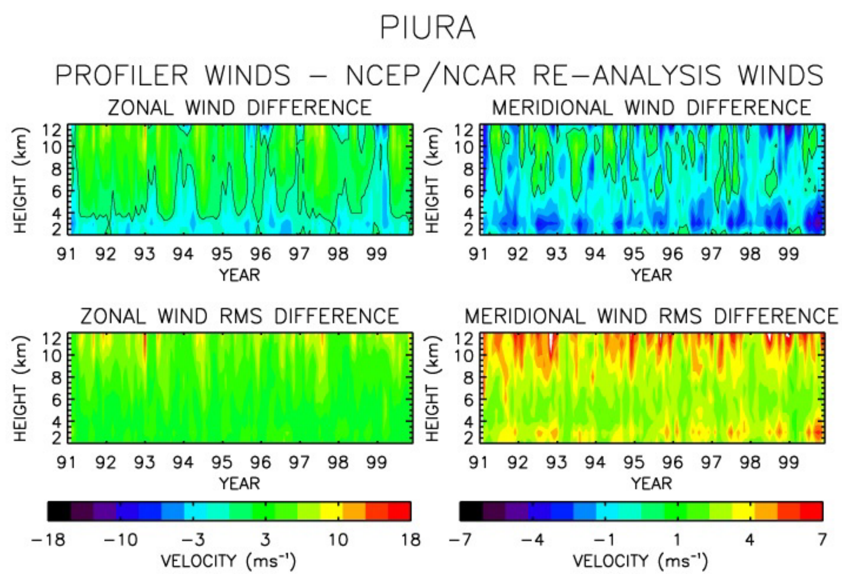
Theme(s): Advanced Observing and Modeling Systems

Payoff: Improved data assimilation products for initialization of weather forecasting models.

Funding Sources: NOAA, NSF

Improvement in weather prediction is often associated with improvements in observations that are assimilated into the forecast process, new computational power that allows for higher model resolution, and new understandings of physical processes that are incorporated into the forecast model. Wind profiling radar observations in the United States have routinely been incorporated into the data assimilation used in weather forecasting. However, equatorial wind profiler observations have seen limited use in the assimilation process even though several sites in the tropical Pacific have been in operation since the early 1980's. Use of these observations in a region that has sparse radiosonde coverage may very well help to improve global weather prediction. In order to determine the impact of these equatorial winds, an investigation was done that examined the agreement between winds over the tropical Pacific derived from the NCEP/NCAR reanalysis model with those observed from the equatorial wind profilers.

As expected, the closest agreement between reanalysis derived winds and profiler measured winds occurs at Christmas Island (Republic of Kiribati) where the observations are already assimilated into the reanalysis. Good agreement also occurs at Darwin (Australia) and Biak (Indonesia) where radiosonde wind data is available for data assimilation. At Piura (Peru), the atmospheric wave effects from the Andes mountain range in conjunction with a lack of radiosonde observations leads to a significant difference between the wind profiler and reanalysis measurements, especially in the meridional wind field as seen in the figure, with a root mean square difference of up to 7 m/s, a bias of up to ±4 m/s, and a correlation of less than 0.5. Based on this analysis, incorporation of the Piura wind profiler data could potentially improve the model results by at least 50%.



Improved Rainfall Estimations Using X-band Radar Polarimetric Measurements

Project Personnel: S.Y. Matrosov, K.A. Clark, W. C. Campbell

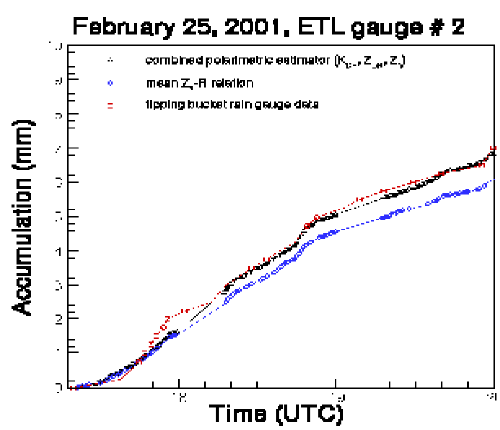
Theme(s): Advanced Observing and Modeling Systems

Payoff: More accurate rainfall estimates with better spatial resolution

Funding Source: NASA

Obtaining reliable quantitative estimates of rainfall parameters from radar measurements remains to be a major task of radar meteorology. Traditional algorithms based on relating radar reflectivity (Z) and rainfall rate (R) are characterized by significant uncertainties. Recent technological advances in radar polarimetry stimulated developments of rain retrieval algorithms that use new radar polarization parameters such as differential propagation phase shift (KDP) and differential reflectivity (ZDR). These developments were mostly intended for the use with longer wavelength radars such as those at S (10 cm) and C (5 cm) bands. The Z-R relation based use of X (3 cm) band radars for the quantitative measurements of rainfall was limited until recently due to attenuation affects. The differential phase shift capability, however, overcomes this limitation since it provides a robust way to account for partial attenuation. X band wavelengths also offer some advantages compared to longer wavelengths such as stronger KDP signals. This results in better accuracy in measurements of light and moderate rains. The mobility of X-band radars also makes them a convenient tool for different filed projects when high-resolution rainfall mapping is essential.

The NOAA ETL's transportable Doppler polarimetric radar was taken to NASA's Wallops Island facility in Virginia at the end of February 2001, to conduct an 8-week-long precipitation measurements campaign. One of the experiment objectives was testing different rainfall rate estimators including the polarimetric, one that was specifically tailored for X-band wavelengths. The figure below shows rain accumulation vs. time for a 3-hour period of light to moderate rainfall. Here the rain gauge on the ground directly below the radar's sensing volume is taken as "truth" (red line). Radar-derived accumulation using the new combined polarimetric technique (black line) and a typical Z-R relationship (blue line) are shown. As expected, the polarimetric estimator provided overall better agreement with gauge data. Averaged over all cases at Wallops, radar retrievals of total accumulation using the new combined polarimetric technique generally agree with the rain gauges to within 25% which is much better than for Z-R relation algorithms.



New Process for Rapid Micronization and Drying of Proteins and Pharmaceuticals

Project Personnel: R.E.Sievers, E.T.S.Huang, J.A.Villa, G.Engling and T.R.Walsh

Theme(s): Advanced Observing and Modeling Systems

Payoff: Developing an important new mechanism for administering drugs through inhalation

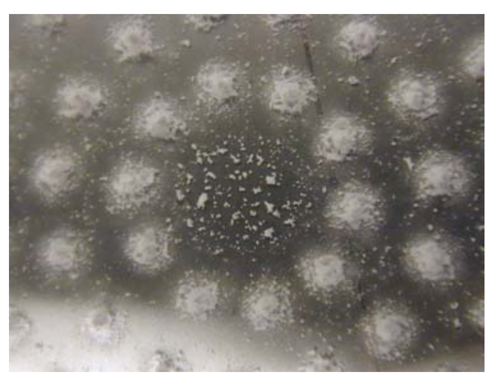
Funding Sources: Colorado Tobacco Research Program

A new technology rapidly produces and dries fine particles of drugs and proteins that can be administered into the lungs. A laboratory-scale version of the Bubble Dryer™ is being manufactured and larger-scale models are currently in the engineering stage. The Bubble Dryer™ generates particles in three to five seconds that range from one to three microns in diameter. This is the size required for pulmonary delivery of drugs into the alveoli of the lungs. This technology is currently being widely considered because pulmonary delivery eliminates the need for needles required for intravenous drug delivery and avoids the problem of destruction of the drug in the stomach. Drugs can be delivered either directly into the alveoli to treat lung diseases like emphysema and cystic fibrosis, or they can act systemically, for example, to treat diabetes with inhaled insulin. Furthermore, this technology offers a remarkable improvement over conventional micronization methods, which often produce particles that are too large for efficient pulmonary delivery.

Several techniques exist for drying proteins and creating very fine particles of drugs for pulmonary delivery. However, the drawbacks to these procedures are significant and, in some cases, severely limit the number of proteins and drugs that can be micronized. First, classic procedures such as freeze-drying are time-intensive and can take hours per run to complete. Second, many procedures depend on solvents and dispersants such as methylene chloride that leave residues, are environmentally unsound, and are dangerous to workers. Finally, procedures such as classical spray drying require high temperatures that may degrade or inactivate the end product.

The Bubble Dryer™ provides a solution to these problems. The process uses only three ingredients: carbon dioxide, the drug or protein to be micronized, and either water or ethanol as the solvent. Intimate mixing of the aqueous solution and liquid carbon dioxide causes the formation of microbubbles, which are rapidly dried in less than five seconds. And, since the Bubble Dryer™ is effective at milder temperatures than are involved in spray drying, protein denaturation is avoided and energy consumption is reduced. In some cases, pressurizing and nebulizing enzymes with CO_2 actually increases enzyme activity.

This technology has been explored using a wide variety of substrates, including proteins stabilized in sugar matrices. Examples of 1-3 micron particles that have been made include: Pulmozyme, ovalbumin in trehalose, lactate dehydrogenase, trypsinogen, lysozyme, budesonide, albuterol sulfate, chromolyn sulfate, tobramycin sulfate, Amphotericin B, cyclosporin and Naproxen.



Negative Ion Mass Spectrometry for Detection of HCN and Carbonyls from Vegetation

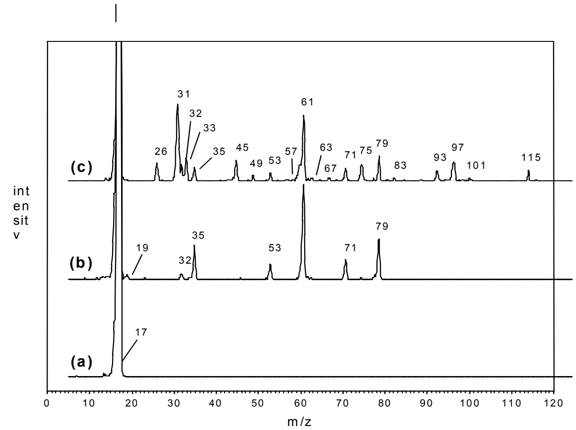
Project Personnel: T.G. Custer, S. Kato, V.M. Bierbaum, and R. Fall

Theme(s): Advanced Observing and Modeling Systems; Planetary Metabolism

Payoff: A new method for analysis of biogenic volatiles that are indicators of biomass burning

Funding Source: CIRES Innovative Research Program

Volatile organic compounds (VOCs) play an important role in the chemistry of the earth's atmosphere where they participate in the formation of ozone, aerosols, radicals, and organic nitrates. Thus, a detailed characterization of the biogenic sources of VOCs has become a major goal of both laboratory and field measurements. In addition, VOCs and other non-organic volatiles such as hydrogen cyanide (HCN) are released by biomass burning and forest fires, and can be used as atmospheric tracers for these combustion sources. Proton transfer-chemical ionization mass spectrometry (PT-CIMS) has been shown to be a powerful method for the on-line, simultaneous detection of VOC emissions from biogenic sources. PT-CIMS utilizes proton transfer reactions from H_3O^+, usually in a drift tube, to provide an efficient, sensitive, and general method for the detection of many VOCs. However, the existence of overlapping masses and the occurrence of product ion fragmentation can complicate the mass spectra and obscure the identity of some compounds. We have therefore explored the applicability of negative ion-chemical ionization mass spectrometry (NI-CIMS), utilizing proton abstraction reactions with HO^- at thermal energy, for on-line monitoring and identification of VOCs and HCN. Negative ion chemistry offers several potentially valuable features: (1) Negative ions generally retain their isomeric identity, in contrast to protonated cations where the high proton mobility leads to well known rearrangements and dehydrations within the drift region of an instrument. (2) Negative ions often exhibit isomer-specific chemistry and collision-induced dissociation processes and can thus be identified by their reactions. (3) Negative ion chemistry utilizing HO^- can provide sensitive detection of several compounds, such as CO_2 and HCN, which are difficult to detect with PT-CIMS employing the H_3O^+ reagent ion.



Negative ion mass spectra showing a) injection of the reagent ion OH⁻; b) addition of laboratory air; and c) addition of headscape air from wounded clover leaves. In c) the ion at mass26 has been identified as CN⁻ arising from cyanogenic precursors in leaves, and other ions represent various VOC's produced by wounding.

We have demonstrated that NI-CIMS can be used to distinguish several isomeric volatile organic compounds (VOCs) that are emitted from wounded plants. Reaction chemistry with HO^-, hydrogen/deuterium exchange patterns, and collision-induced dissociation spectra allow identification of the isomers. Laboratory studies of emissions from wounded clover using NI-CIMS show several previously detected VOCs, but also clearly demonstrate the emission of HCN (Figure 1). This compound is presumably formed by the decomposition of cyanogenic glycosides that also form aldehyde and ketone byproducts. Our studies suggest that the wounding and drying of plants may be an important additional source of HCN that should be included in a comprehensive model of the earth's atmosphere. These results also suggest that NI-CIMS may be a valuable tool for investigating and detecting VOCs and HCN release from biomass burning and forest fires.

Sensitivity and Specificity of Atmospheric Trace Gas Detection Using PTR-MS

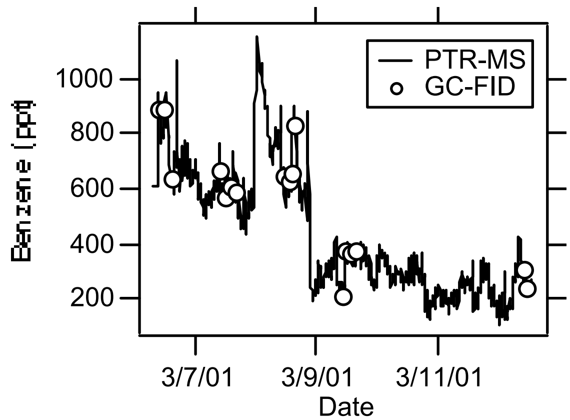
Project Personnel: Joost de Gouw

Theme(s): Advanced Observing and Modeling Systems

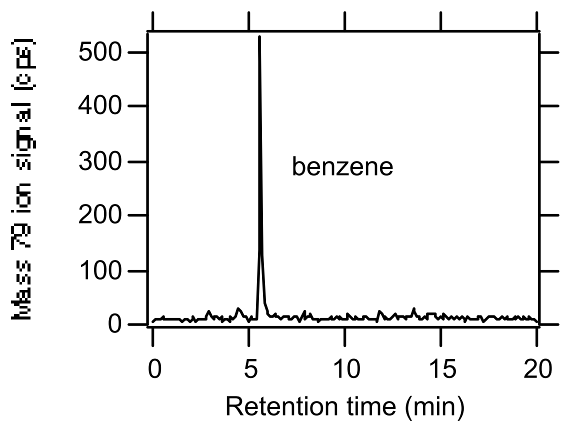
Payoff: Fast time-response measurements of volatile organic compounds in the atmosphere

Funding Source: NOAA

Proton-transfer-reaction mass spectrometry (PTR-MS) is a novel technique for on-line measurements of volatile organic compounds (VOCs) in air with a high sensitivity (10-100 ppt) and a fast time response (1-3 s). The technique allows simultaneous measurements of a host of atmospheric VOCs from anthropogenic and biogenic sources and in addition their atmospheric oxidation products. PTR-MS is therefore well suited to study the atmospheric photo-oxidation of VOCs, which play an important role in the formation of ozone and aerosols in the troposphere.



Work is in progress to characterize the sensitivity and selectivity of atmospheric VOC measurements by PTR-MS. The figure below shows an inter-comparison between PTR-MS measurements of benzene in urban air and the results of gas chromatographic (GC) analyses of a number of air samples taken during the same period. The figure shows that the agreement between the two methods is good, and clearly demonstrates the improved level of detail that can be obtained using PTR-MS in comparison with GC measurements. To investigate possible interferences, a GC column has been coupled to the PTR-MS instrument to analyze individual samples. The figure below shows a chromatogram thus obtained, which demonstrates that only benzene contributes significantly to the signal. Other VOCs included in this study are methanol, acetonitrile, acetaldehyde, acetone, DMS, isoprene, toluene and the higher aromatics.



In 2002, CIRES scientists plan to deploy PTR-MS and other instruments onboard a NOAA WP-3 research aircraft to study the long-range transport of air masses from Asia towards the west coast of the U.S. In addition, ground–based measurements will be performed in New Hampshire to study air quality and regional haze problems in New England.

Direct Solar Spectral Irradiance and Transmittance Measurements from 350 to 2500 nm

Project Personnel: B.C. Kindel, Zheng Qu, A. F. H Goetz

Theme(s): Advanced Observing and Modeling Systems

Payoff: Better atmospheric correction for optical remote sensing systems for studying surface processes

Funding Sources: NASA, CIRES

For many years, CSES has been funded by NASA to develop better atmospheric correction models, in particular, for developing hyperspectral imaging systems. One of the persistent unknowns has been the surface spectral irradiance to enter into the R-T models. The goal has always been to derive all the model information from the hyperspectral data themselves. However, when the model does not yield the correct answer, a separate measurement is required. We have been successful in deriving instantaneous atmospheric transmittance during aircraft and satellite overpasses using a portable spectrometer and a unique method for calibration.

A radiometrically stable, commercially available spectroradiometer was used in conjunction with a simple, custom-designed telescope to make spectrally continuous measurements of solar spectral transmittance and directly transmitted solar spectral irradiance. The wavelength range of the instrument id 350-2500 nm and the resolution is 3-11.7 nm. A method of absolute radiometric calibration that can be tied to published, top-of-the –atmosphere solar spectra in valid Langley channels as well as regions of strong molecular absorption was developed. Example comparisons of measured and MODTRAN-modeled direct solar irradiance show that the model can be parameterized to agree with measurements over the large majority of the wavelength range to the 3% level for the two example cases. Side-by-side comparisons with a filter-based solar radiometer are in excellent agreement, with a mean absolute difference of $\tau = 0.0036$ for eight overlapping wavelengths over three experiment days.

Impact of Small Scale E-field Variability on the Energy Budget of the Thermosphere

Project Personnel: M. V. Codrescu and T.J. Fuller-Rowell

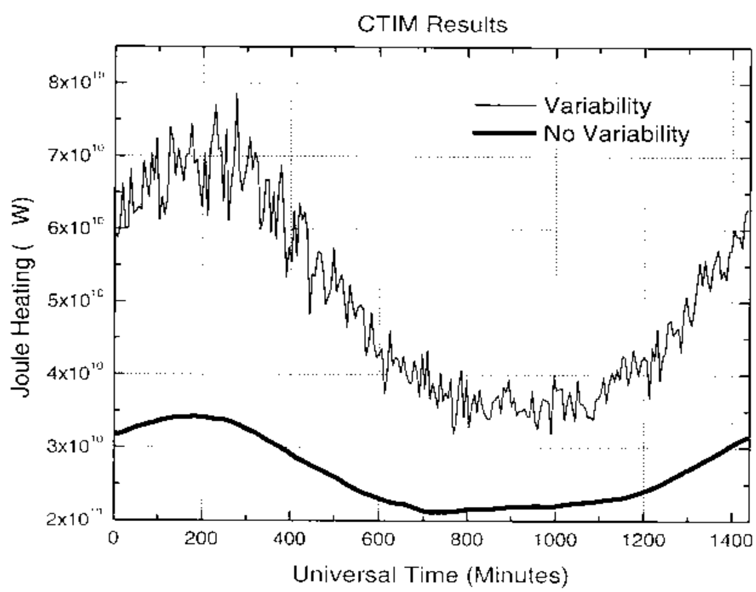
Theme(s): Advanced Observing and Modeling Systems

Payoff: Improved understanding of the physics and better space weather forecasting models.

General circulation models (GCMs) of the thermosphere underestimate the high-latitude energy source if Joule heating calculations include only the average electric field and do not consider the variability associated with the averages. The temperature structure, as reflected in the position of the global minimum and maximum areas and the chemical composition reflected in the latitudinal mean molecular mass structure in the mass spectrometer and incoherent scatter (MSIS) empirical model were not reproduced by the coupled thermosphere ionosphere model (CTIM) GCM when only average E-fields were considered.

The underestimation of the high-latitude energy input can be explained based on theoretical considerations. It is known that the high-latitude electric fields are variable on a variety of spatial and temporal scales. The characteristics of the variability are not well known, and therefore only average values for the E field are used to compute Joule heating in GCMs. Since the amount of Joule heating is proportional to the average of the square of the E field, neglecting the variability leads to an underestimation of the high-latitude energy input.

The model of the average convection electric fields used in CTIM was obtained by sorting incoherent scatter radar observations of line of sight plasma drift from Millstone Hill, as a function of the precipitating particle activity index, magnetic latitude, and local time. We reanalyzed the same set of Millstone Hill observations used in the original electric field model and we were able to produce the average patterns and the associated bin standard deviations. The standard deviations were used to parameterize the small-scale variability in recent runs of the GCM. The figure below illustrates the difference in Joule heating between the runs with and without the inclusion of variability.



Empirical Modeling of the Ionospheric Response to Geomagnetic Storms

Project Personnel: Tim Fuller-Rowell, Eduardo Araujo-Pradere, and Mihail Codrescu

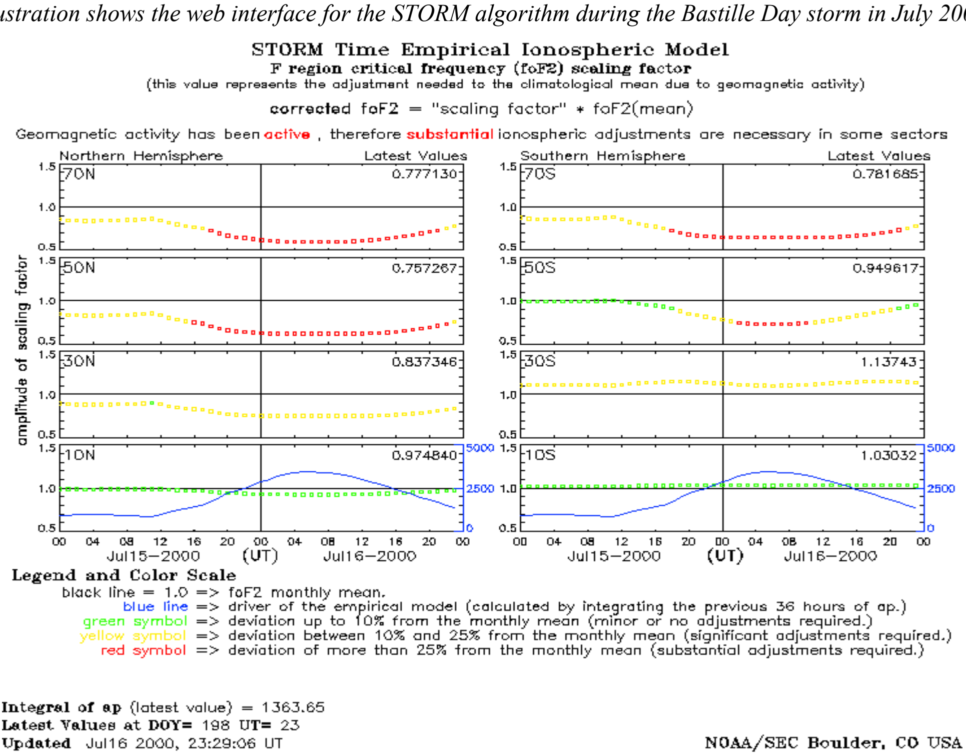
Theme: Advanced Observing and Modeling Systems.

Payoff: Providing support to HF communication users

Transitioning of scientific understanding for the benefit of society has always presented a challenge. This is certainly true at NOAA's Space Environment Center where efforts continue to improve forecasts of solar and geomagnetic activity, and to determine the impact on the upper atmosphere. Recent theoretical model simulations of the ionospheric response to geomagnetic storms have provided the understanding for the development of the first empirical storm-time ionospheric correction model (STORM).

The model provides the storm-time correction to the F-region critical frequency, which is primarily of benefit to high frequency (HF; 3-30 MHz) communication users. During a geomagnetic storm the F-region ionosphere can be either depleted or enhanced. When the ionosphere is enhanced, higher communication frequencies can be used, enabling a reduction in absorption and an increase in signal strength. If the ionosphere is depleted, the maximum usable communication frequencies must be reduced to ensure reflection of the radio signal by the ionosphere to the receiver. The empirical model is driven by the previous time-history of a_p, and is designed to scale the quiet-time F-layer critical frequency (foF2) to account for storm-time changes in the ionosphere. The model provides a useful, yet simple tool for estimating the changes to ionosphere in response to geomagnetic activity. The STORM correction model has been implemented on the SEC web page, in real-time, providing a robust ionospheric correction. The figure below illustrates the web interface to the STORM model. The example shown is the model prediction for the Bastille Day (July 2000) storm. With a maximum negative D_{st} of -290 nT and an a_p of 400, this magnetic perturbation was the strongest of year 2000.

Illustration shows the web interface for the STORM algorithm during the Bastille Day storm in July 2000.



High Resolution Imaging of Crust and Mantle Seismic Velocity Discontinuity Structure

Project Personnel: A. Sheehan, C. Jones, H. Gilbert, C. Wilson

Theme(s): Advanced Observing and Modeling Systems; Geodynamics

Payoff: Improved Earth subsurface images for understanding of mantle dynamics, earthquake hazards, geothermal resources

Funding Sources: NSF, US Navy Geothermal Programs office

Common midpoint (CMP) stacking of records of P-SV seismic converted phases (receiver functions) from radial velocity layering in the Earth has become a widespread technique for high resolution imaging of crust and deep mantle discontinuities (e.g., Dueker and Sheehan, 1997, 1998; Li and Fischer, 1998; Shen et al., 1998; Wilson et al., 2001). By stacking many receiver functions, which sample the same subsurface point, signal to noise is dramatically improved and small amplitude features can be resolved. These techniques have led to high-resolution images of mantle discontinuity topography, and have shown that discontinuity topography can be significant (20-30 km) over wavelengths of a few hundred kilometers. The CMP technique implicitly assumes that all P-SV conversions are produced by flat lying, laterally continuous structures, and does not take into account diffraction effects and focusing produced by curved or laterally discontinuous interfaces. The seismic reflection community has long recognized the importance of migrating reflected phases back to their appropriate origin point. Seismic migration eliminates artifacts produced by inappropriate assumptions of horizontal planar structure, and produces dramatic improvements in reflection image quality (e.g. Claerbout, 1992). We have developed migration techniques and applied them to receiver functions, with particular application to data from the 1993 Snake River Plain (SRP) IRIS PASSCAL seismic experiment (Dueker et al., 1993). Synthetic experiments presented here show that dramatic improvement over simple CMP stacking can be achieved through back projection migration processing applied to receiver functions. This work also demonstrates the importance of random resampling tests to determine the robustness of subtle features. Receiver function images from other recent and ongoing Western United States passive seismic deployments with both linear and two-dimensional geometries have been analyzed, including a high-resolution deployment at the Coso geothermal area in California. The proposed US Array experiment of thousands of broadband receivers across the United States would provide a wealth of data for analyses of the type outlined here.

Preparing for Time-Variable Gravity Measurements from the GRACE Satellite

Project Personnel: J. Wahr, I. Velicogna, S. Jayne, S. Swenson

Theme(s): Advanced Observing and Modeling Systems

Payoff: NASA

NASA, in partnership with the German Space Agency DLR, will launch the dedicated gravity satellite GRACE near the end of 2001. This five-year mission will map out the Earth's gravity field to unprecedented accuracy at monthly intervals. The temporal variations in gravity inferred from these data will allow people to study a wide range of processes, cutting across a variety of Earth science disciplines that involve redistribution of mass within the Earth and at or near its surface. It will be possible, for example, to produce monthly estimates of changes in continental water storage anywhere in the world, averaged over scales of a few hundred km and greater, to accuracies of better than 1 cm water thickness. Changes in the distribution of snow and ice on the polar ice sheets will be determined to this same level of accuracy. Monthly estimates of changes in sea floor pressure over scales of a few hundred km and greater will be determined to a few tenths of a mbar or better, everywhere over the globe.

The effects of the solid Earth's viscoelastic response to the removal of the enormous late Pleistocene ice sheets and to the Holocene fluctuations of the Antarctic and Greenland ice sheets can be determined. CIRES is taking a leading role in exploring the possible applications of this novel technique, developing methods for converting the GRACE gravity fields into useful measurements of mass redistribution, and looking at ways of combining GRACE measurements with measurements from other techniques (i.e. the satellite radar altimeter measurements of sea surface height; GLAS laser altimeter measurements of ice sheet elevations; GPS crustal motion measurements) to optimize the scientific return.

A Suspended Fabry-Perot Interferometer for Determining the Newtonian Constant of Gravitation

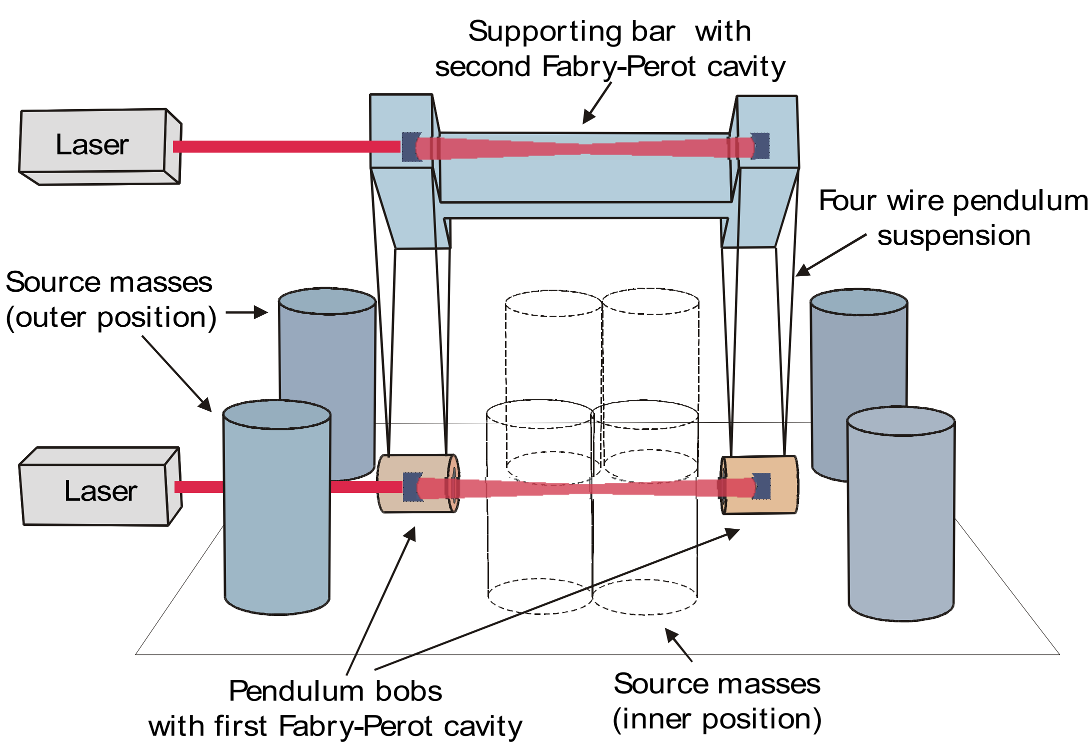
Project Personnel: H. V. Parks, D.S. Robertson, A.M. Pattee, and J.E. Faller

Theme(s): Advanced Observing and Modeling Systems; Geodynamics

Payoff: Improved knowledge of fundamental constants, novel metrology techniques

Funding Source: NIST, NOAA

Of all the fundamental constants of nature, the Newtonian constant of gravitation, G, has been one of the most difficult to measure. The current CODATA value of G has an uncertainty of 1.5 parts in 1000. Although recent experiments have produced values with uncertainties smaller than this, the CODATA value reflects the fact that there is still substantial disagreement between the values from these experiments. The majority of previous measurements have used torsion pendulums or balances to convert the small gravitational attraction of a laboratory source mass into a relatively large mechanical displacement. However, our approach is to use simple pendulums, which results in a small displacement that we measure very accurately. This means that the attraction of the source masses is measured against a restoring force provided by earth's gravity rather than the less well-understood torsion of a wire. Also, the shorter period of our pendulums allows us to make measurements much more rapidly than in most other experiments. In our apparatus, two mirrors, each suspended as a simple pendulum, form a Fabry-Perot cavity. A He-Ne laser locked to this cavity monitors the relative displacement of these two pendulums (through changes in its frequency) as laboratory source masses are moved, altering the gravitational pull on the mirrors.



Seismo-acoustic Interface Waves in Unconsolidated Marine Sediments

Project Personnel: O. A. Godin and D. M. F. Chapman

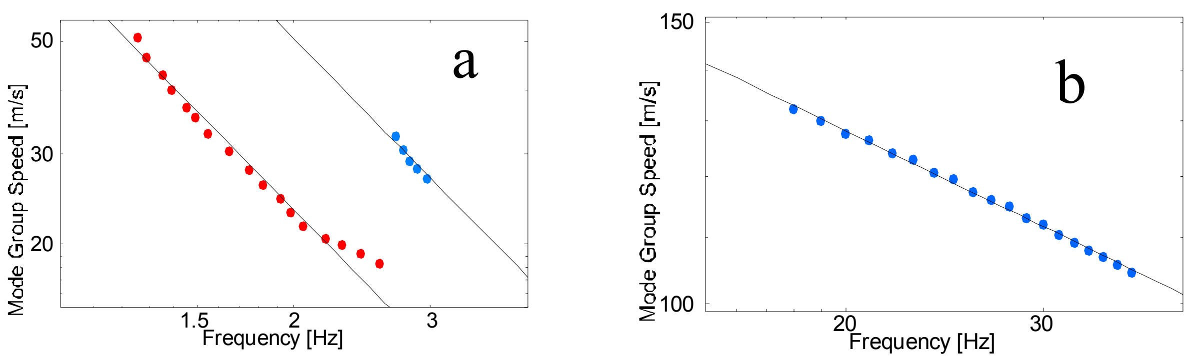
Theme(s): Advanced Observing and Modeling Systems

Payoff: Improved techniques to measure geoacoustic properties of the sea floor

Funding Sources: NOAA, NRC

In the upper tens of meters of ocean bottom, unconsolidated marine sediments consisting of clay, silt, or fine sand with high porosity are "almost incompressible" in the sense that the shear wave velocity is much smaller than the compressional wave velocity. The shear velocity has very large gradients close to the ocean floor leading to strong coupling of compressional and shear waves in such "soft" sediments. The weak compressibility opens an avenue for developing a theory of elastic wave propagation in continuously stratified soft sediments that fully accounts for the coupling. Elastic waves in soft sediments consist of "fast" waves propagating with velocities close to the compressional velocity and "slow" waves propagating with velocities on the order of the shear velocity. For the slow waves, our theory predicts existence of surface waves at the ocean-sediment boundary. In the important special case of the power-law depth-dependence of shear rigidity, phase and group velocities of the interface waves are shown to scale as a certain power of frequency. An explicit, exact solution was obtained for the surface waves in sediments characterized by constant density and a linear increase of shear rigidity with depth. Theoretical dispersion relations agreed well with numerical simulations and available experimental data and led to a simple and robust inversion of interface wave travel times for shear-velocity profiles in the sediment.

The practical significance of seismo-acoustic interface waves consists in the fact that their travel times can be inverted for geotechnical and geoacoustic properties of the sea floor that are difficult to measure by other means.



Agreement between theoretical predictions of the group velocity of seismo-acoustic interface waves (lines) and experimental data (dots) for sites on the Canadian Eastern Shore (a) and in the Gulf of Mexico (b)

Simulations of Complex Earthquake Fault Systems for Physics and Forecasting

Project Personnel: J.B. Rundle, P.B. Rundle, K.F. Tiampo, J. S. Martins

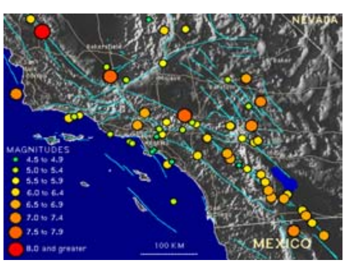
Theme(s): Advanced Observing and Modeling Systems

Payoff: Elucidating the basic physics of complex, interacting earthquake fault systems, with potential applications in earthquake forecasting.

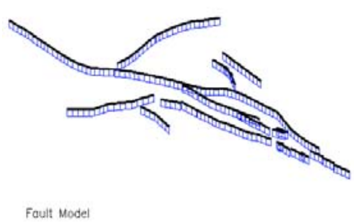
Funding Sources: DOE, NASA, NSF

Background: Understanding the physics of earthquakes is essential if large events are ever to be forecast. Real faults occur in topologically complex networks that exhibit cooperative, emergent space-time behavior that includes precursory quiescence or activation, and clustering of events. The purpose of our work is to construct and examine the dynamics of realistic earthquake fault networks, and to investigate the sensitivity of emergent behavior to changes in the physics on the scale of single faults or smaller. We therefore need to construct models of earthquake fault systems that contain the essential physics. To do so, a network topology is defined in an elastic medium, the stress Green's functions (i.e. the stress transfer coefficients) are computed, frictional properties are defined and the system is driven via motions of the tectonic plates. We focus in this work on the major strike-slip faults in Southern California that produce the most frequent and largest magnitude events. To determine the topology, properties, and characteristics of the network, we used tabulations of fault properties that have been published in the literature.

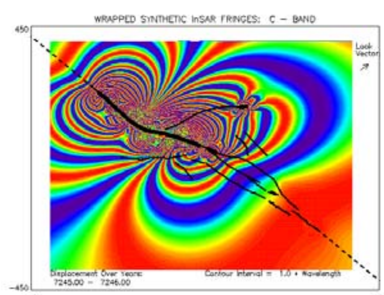
Results: We have found that the statistical distribution of large earthquakes on a model of a topologically complex, strongly correlated real fault network is highly sensitive to the precise nature of the stress dissipation properties of the friction laws associated with individual faults. These emergent, self-organizing space-time modes of behavior are properties of the network as a whole, rather than of the individual fault segments of which the network is comprised.



Historic data & faults in Southern California



Model fault topology in Southern California



InSAR fringes from simulated earthquake

Field Reflectance Spectrometry for Detection of Swelling Clays at Construction Sites

Project Personnel: A.F.H Goetz, S. Chabrillat

Theme(s): Advanced Observing and Modeling Systems

Payoff: Potential for revolutionizing the techniques for determining soil properties that currently are time consuming and expensive

Funding Source: NASA

Along Colorado's Front Range and in other parts of the country and the world, soils containing high amounts of smectites, clays that attract water into the interlayers and swell, are a hazard to construction. Soil tests often take days to weeks to perform and because of the cost are not generally done at a narrow spacing.

We have developed techniques to map the distribution and composition of clay-rich soils with portable field spectrometers on the ground. Spectral reflectance measurements in the 1800-2400 nm region with 10 nm resolution can distinguish smectites, which cause swelling, from illites and kaolinite that do not swell significantly. Illites and smectites are often mixed in the soil and result in varying swell potential. Standard engineering soil tests are too time consuming and costly to be used in areas where there is highly varying swell potential. Therefore, in many instances in regions of steeply dipping sedimentary layers, beds of swelling clay go undetected. We show that it is possible to determine smectite content with a standard cross-validation error of 10% based on partial least squares analysis of second-derivative reflectance spectra. Loadings show that the 1800-2000 and 2150-2250 nm regions contain the most relevant information for the detection and quantification of smectite content and these correspond to the bound water in the clay lattice interlayer and the Al-OH combination band respectively. Correlations as high as 87% were obtained with the Seed swell-potential index. The correlations are higher when the samples were dried rather than measured in their moist condition shortly after collection in the field, as in an earlier study. Correlation with other swell indices shows that reflectance spectroscopy would be a reliable indicator that could divide samples into low, medium and high swell potential. The effect of sample moisture was studied and the results show that the surface of the field samples must first be dried before measurement, in order to obtain a reliable swell potential value from the model.

Direct Solar spectral Irradiance and Transmittance Measurements from 350 to 2500 nm

Project Personnel: B.C. Kindel, Zheng Qu, A. F. H Goetz

Theme(s): Advanced Observing and Modeling Systems

Payoff: Better atmospheric correction for optical remote sensing systems for studying surface processes

Funding Sources: NASA, CIRES

For many years, the Center for the Study of Earth from Space (CSES) has been funded by NASA to develop better atmospheric correction models, in particular for hyperspectral imaging systems. One of the persistent unknowns has been the surface spectral irradiance to enter into the R-T models. The goal has always been to derive all the model information from the hyperspectral data themselves. However, when the model does not yield the correct answer, a separate measurement is required. We have been successful in deriving instantaneous atmospheric transmittance during aircraft and satellite overpasses using a portable spectrometer and a unique method for calibration.

A radiometrically stable, commercially available spectroradiometer was used in conjunction with a simple, custom-designed telescope to make spectrally continuous measurements of solar spectral transmittance and directly transmitted solar spectral irradiance. The wavelength range of the instrument id 350-2500 nm and the resolution is 3-11.7 nm. A method of absolute radiometric calibration that can be tied to published, top-of-the-atmosphere solar spectra in valid Langley channels as well as regions of strong molecular absorption was developed. Example comparisons of measured and MODTRAN-modeled direct solar irradiance show that the model can be parameterized to agree with measurements over the large majority of the wavelength range to the 3% level for the two example cases. Side-by-side comparisons with a filter-based solar radiometer are in excellent agreement, with a mean absolute difference of $\tau = 0.0036$ for eight overlapping wavelengths over three experiment days.

An Operational 20-km Version of the Rapid Update Cycle

Project Personnel: S. Benjamin, D. Devenyi, G. Grell, D. Kim, T. Smirnova

Theme: Advanced Observing and Modeling Systems

Payoff: Operational improvements in forecasts of warm- and cold-season precipitation, cloud and icing forecasts, and hourly surface conditions.

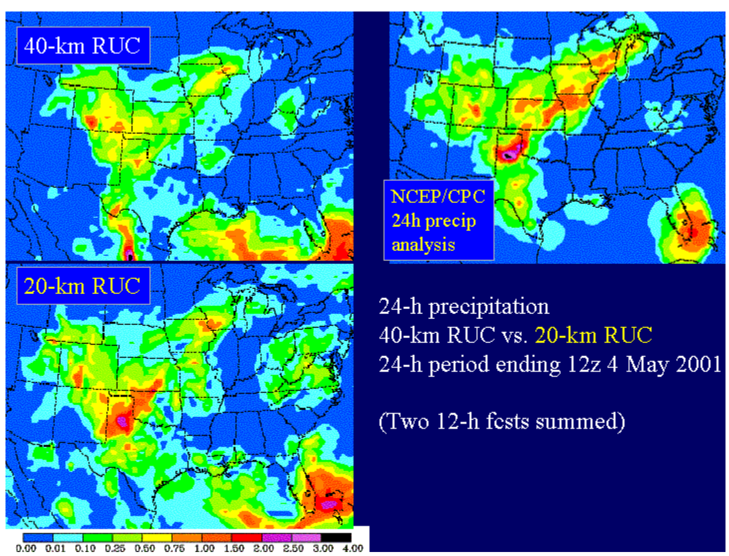
Funding Sources: NOAA, FAA, NSF

The Rapid Update Cycle (RUC) is a system for updating analyses of surface, tropospheric and lower stratospheric conditions every hour over the lower 48 United States and adjacent areas. From these analyses, short-term forecasts out to twelve hours are produced for use by aviation, National Weather Service Forecast offices, and a variety of other customers. The RUC has been operational at NOAA's National Centers for Environmental Prediction (NCEP) since 1994 and is currently undergoing its second major revision.

Among the major revisions:

- Increase in horizontal resolution from 40 km to 20 km and in vertical resolution from 40 to 50 levels
- Conversion from optimum interpolation to three-dimensional variational analysis (Devenyi); this makes it much easier to assimilate observations of variables not explicitly predicted by the model.
- New cloud microphysics that reduces excessive production of graupel and leads to more realistic concentrations of supercooled cloud droplets that can cause aircraft icing
- Use of data from GOES satellites to improve the initial cloud field (Kim)
- New scheme for representing sub-grid scale effects of convection (Grell)
- Improved soil model and a two-level snow model (Smirnova)
- Incorporation of high-resolution land-use data from the U.S. Geological Survey

The revisions have led to better forecasts of precipitation; the diurnal cycle of temperature, humidity, and wind at the ground; and aircraft icing. The figure illustrates a striking improvement in the forecast of a heavy rain event.



Appendices - CIRES Committees 2000-2001

Council of Fellows

Susan Avery Rajagopalan Balaji Ben Balsley Roger Barry John Birks Roger Bilham Thomas Chase Shelley Copley Henry Diaz Randy Dole Chris Fairall Ray Fall Lang Farmer	Fred Fehsenfeld Tim Fuller-Rowell Alex Goetz Vijay Gupta Ted Habermann Mike Hardesty Bill Hay, Emeritus Craig Jones Carl Kisslinger, Emeritus Bill Lewis Amanda Lynch Peter Molnar	Russ Monson Andy Moore Bill Neff Roger Pielke Jr. Uwe Radok, Emeritus George Reid Doug Robertson John Rundle Thomas Schlatter Anne Sheehan Robert Sievers Susan Solomon	Hartmut Spetzler Konrad Steffen Pieter Tans Maggie Tolbert Veronica Vaida John Wahr Peter Webster Carol Wessman *45 total CIRES Fellows* *42 voting* *3 Emeritus*

Executive Committee (2001)

Director Executive Director Associate Directors Jeff Hare, Members' Representative Julia Collins, Members' Representative Shelley Copley (Jan. 01) first term Lang Farmer Russ Monson (Jan. 02) first term William Neff (Jan. 01) first term George Reid (Jan. 02) second term CIRES Staff (Ex-officio)

Members' Council Reps (00/01)

Wayne Angevine Cathy Burgdorf Julia Collins, Member's Rep to Fellows/Exec Mihail Codrescu Rod Frehlich Jeff Hare, Member's Rep to Fellows/Exec Ruth Hobson Michelle Holm Anne Jefferson Anne Nolin Robert Schubert Donna Scott

Associate Directors (00/01)

F. Fehsenfeld (Environmental Chem. and Biology)
R. Bilham (Solid Earth Sciences)
K. Steffen (Cryospheric and Polar Processes)
M. Hardesty (Atmospheric and Climate Dynamics)

Career Track Committee (2000)	***Career Track Committee (2001)***
Anne Sheehan, Chair	Tim Fuller Rowell, Chair
Ben Balsley	Ben Balsley
Tim Fuller Rowell	Bill Neff
Bill Neff	Doug Robertson
Susan Solomon	Veronica Vaida
Ex officio: P. Sperry, L. Walloch, K. DeClerk	Ex officio: P. Sperry, L. Walloch, K. Dempsey

Computing Advisory Committee (2000)	***Computing Advisory Committee (2001)***
Koni Steffen, Chair	Koni Steffen, Chair
Julia Collins	Julia Collins
Rod Frehlich	Rod Frehlich
Leanne Lestak	Leanne Lestak
Amanda Lynch	Robert Schafer
Julie McKie	Julie McKie
Seth McGinnis	John Cassano
Ex-officio: Paul Sperry, Henry Johnson	Ex-officio: Paul Sperry, Henry Johnson

Distinguished Lectureship Series (00/01)

Andy Moore

Gustavson Memorial Lecture Series (00/01)

Amanda Lynch
Patricia Limerick
Jana Milford
Robert Sievers

Fellows Appointment (2000)	***Fellows Appointment (2001)***
Bill Lewis, Chair Andy Moore George Reid John Wahr	Maggie Tolbert, Chair Chris Fairall Russ Monson Andy Moore Hartmut Spetzler

Visiting Fellows Selection (2000)	***Visiting Fellows Selection (2001)***
Amanda Lynch, Chair Craig Jones Pieter Tans	John Rundle, Chair Robert Sievers

Space Committee (2000)
Ben Balsley John Birks Lang Farmer Ex-officio: Lynn Walloch, Robert Schubert

Appendices - CIRES Visiting Fellowship Selections

With sponsorship from the National Oceanic and Atmospheric Administration's Environmental Research Laboratories, the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado at Boulder offers up to six one-year Visiting Fellowships to scientists with research interests in the areas of:

- Physics, chemistry, and dynamics of the Earth system (atmosphere, biosphere, hydrosphere, lithosphere)
- Global and regional environmental change
- Climate system monitoring, diagnostics, and modeling
- Remote sensing and *in-situ* measurement techniques for the Earth system
- Interdisciplinary research themes such as CIRES' Western Water Assessment

Awards may be made to Ph.D. scientists at all levels and faculty planning sabbatical leave. Recent Ph.D. recipients and those affiliated with minority institutions are especially encouraged to apply. The CIRES Visiting Fellows Program provides opportunities for interactions between CIRES scientists and Visiting Fellows to pursue common research interests. Selections for this Visiting Fellows Program are based in part on the likelihood of interactions between the Visiting Fellow and the scientists at CIRES and the degree to which both parties will benefit from the exchange of new ideas. To further this goal, priority is given to candidates with research experience at institutions outside the Boulder scientific community.

Year	Name	Affiliation	Research Mentor(s)	Project Title
2001	Aiken, Christopher	Applied Math	Moore, Andrew	Stochastically Forced Variability of the Antarctic Circumpolar Current
	Ben-Dor, Eyal	Soil Sciences	Goetz, Alexander	Monitoring and Management of Soil Degradation Problems derived from Soil Structural Crust Processes
	Donaldson, James	Chemistry	Vaida, Tolbert	Surface Thermodynamics as well as Rainwater Composition and Sea Surface Coatings
	Kjaergaard, Henrik	Chemistry	Vaida, Solomon	Spectroscopy and Atmospheric Relevance of Water Clusters
	Painter, Thomas	Geography	Steffen, Konrad	Spatio-temporal Distribution of Snow Albedo and Snow Covered Area
	Poveda, German	Hydrology	Gupta, Vijay	Space-time Variability of Soil Moisture and Precipitation in Tropical South America at ENSO Timescales
	Steinberger, Bernhard	Geophysics	Molnar, Wahr	Lithospheric Stresses
	Schulte-Pelkum, Vera	Earth Sciences	Molnar, Sheehan, Jones	Imaging Continental Deformation and Crust-mantle Interaction through Array Analysis of Seismic Wavefields
	Warneke, Carsten	Physics	Fehsenfeld, Fall	Oxygenated Biogenic Hydrocarbons in the Atmosphere

Year	Name	Affiliation	Research Mentor(s)	Project Title
2000	Jain, Shaleen	Civil/ Environmental Engineering	Dole, Neff, Avery	Hydrologic Extremes in W. United States – Understanding and Predicting Climate Related Risks
	Lane, Dana	Oceanography	Fairall, Hardesty, Webster	Stochastic Approaches to Cloud-Radiation
	Lin, Johnny	Atmospheric Sciences	Webster, Lynch	Sensitivity of Global Climate Dynamics to Small-scale Phenomena
	Martins, Jorge	Physics	Rundle	Dynamics of Non-linear Systems
	Pursell, Chris	Chemistry	Tolbert	Examination of Heterogeneous chemical reactions on Ammonium Sulfate Aerosols
	Pyles, David	Atmospheric Sciences	Monson, Neff, Dole	Biosphere-Atmosphere Interactions
	Sierk, Bernd	Natural Sciences	Solomon, Hardesty	Differential Optical Absorption Spectroscopy
	Sonder, Leslie	Earth/Plan Sciences	Jones	Significance of Buoyancy Forces for Cenozoic Deformation of W. United States
1999	Harley, Robert	Chemistry/ Biology	Fehsenfeld, Fred	Sources and Atmospheric Dynamics of Air Pollution
	Holt, Elizabeth	Solid Earth	Farmer, Lang	Fossil Fumaroles and Fast-flow paths for Groundwater in Tonopah Tuff
	Pap, Judit	Atmos/Climate	Fuller-Rowell, Timothy	New approach to Understand the Impact of Solar Variability on Earth's Environment
	Ricciardulli, Lucrezia	Atmos/Climate	Sardeshmukh, Prashant	Proposed Research in Climate Diagnostics and Modeling
	Sokratov, Sergey	Cryospheric/ Polar	Barry, Roger	Relationship of Laboratory and Field Observations of Snow Cover
	Stephens, Britton	Chemistry/ Biology	Tans, Pieter	Atmospheric O2 Measurements from Towers and Aircraft
	Worthington, Richard	Atmos/Climate	Balsley, Ben	VHF Radar in the Lower Atmosphere and CASES 1999 Campaign

Appendices - Graduate Research Fellowship Program

This program is open to CIRES-affiliated Ph.D. candidates (typically in their last year) to enable a greater focus upon their research project. They receive 12 month, nonrenewable awards that include half-time stipends, tuition and partial student health insurance. The summer-month stipend may be augmented by funds from contracts and grants under Graduate School and departmental policy as available.

Year	Name	Affiliation	Research Mentor(s)	Project Title
2001-2001	Cullather, Richard	PAOS	Lynch	Atmospheric Moisture Transport and Freshwater Budget of the Arctic
	Fortin, Tara	CHEM	Tolbert	Laboratory Studies of Atmospheric Aerosols
	Golubiewski, Nancy	EPOB	Wessman	Urban Sprawl in Colorado's Front Range: Net Primary Productivity and Carbon Storage
	Hintze, Paul	CHEM	Vaida	The Spectroscopic Properties of Gas Phase Sulfuric Acid
	Koch, Linda	CHEM	Ravishankara	A Missing Link in the CLAW Hypothesis: DMS Oxidation
	McGrath, Claire	EPOB	Lewis	Mechanisms for the Displacement of Greenback Cutthroat Trout by Brook Trout
	Rosenstiel, Todd	EPOB	Monson	Metabolic Regulation of Ionosphere Emission
2000-2001	Box, Jason E.	GEOG	Steffen	Sublimation on Greenland Ice Sheet
	Fletcher, Sara	BIOCHEM	Tans	Inverse Modeling of Multiple Gases in the Troposphere Using Novel Constraints
	Froyd, Karl	CHEM	Ravishankara	Ion-induced Nucleation: The Role of Cluster Ions Containing NH3, H2S04 & H20
	Gilbert, Hersh	GEOL	Sheehan	Upper Mantle Imaging
	Kaushal, Sujay	EPOB	Lewis	Investigation of the Ecological Significance of Dissolved Organic Nitrogen to Heterotrophic Microbial Communities in Streams
	Lerner, Brian	CHEM	Birks	Development of Detection Systems for the In-Situ Chemical Characterization of Aerosol

Year	Name	Affiliation	Research Mentor(s)	Project Title
1999-2000	Anderson, Wendy C.	CHEM	Sievers	Supercritical Fluid Extraction of Actinide Surrogates from Environmental Matrices
	Bailey, David Anthony	PAOS	Lynch	Atmospheric-Ice-Ocean Modeling in Polar Regions
	Custer, Thomas			
	Fisher, Alison J.	CHEM	Fall	Isoprene and Methylbutenol Production in Plants
	Jacobsen, Steven D.	GEOL	Spetzler	Elastic Properties of Minerals at Extreme Conditions
	Martinez-Alonso, Sara	GEOL	Goetz	Spectrometry of Phyllosilicates to Estimate Temperature of Mineralization of Hydrothermal Deposits
	Swenson, Sean	PHYS	Wahr	Atmospheric Effects on Gravity
	Tiampo, Kristy F.	GEOL	Rundle	Pattern Dynamics Analysis of Southern California
	Wilson, Kevin			
1998-1999	Bailey, David Anthony	PAOS	Lynch	Atmospheric-Ice-Ocean Modeling in Polar Regions
	Baker, Bradly	CHEM	Fall	Biogenic Emissions of Oxygenated Volatile Organic Compounds
	Bendick, Rebecca	GEOL	Bilham	
	Boulter, James E.	CHEM	Birks	Real-time Elemental Analysis of Ambient Tropospheric Aerosols
	Grimsdell, Alison	PAOS	Angevine	Afternoon Transition of the Convective Boundary Layer
	Hudson, Paula K.	CHEM	Tolbert	Interaction of Oxygenated Hydrocarbons with Sulfuric Acid Films
	Miller, John B.	CHEM	Tans	13C/12C Ration in Atmospheric Methane
	Niyogi, Dev	CHEM/EPOB	Lewis	Ecosystem Response to Stress in Streams Affected by Mine Drainage

Appendices - Graduate Research Fellowship Program (GRFP) Awardees

1996-1997

Lisa Campbell
Julie Chang
Courtney Hilliard
Mercedes Huaman
Andrew Hudak
Eric Leuliette
Anthony Prenni
Mark Tamisiea
William Waite
Ling Xu
Roberta Yuhas

1997-1998

Krishna Foster
Jill Gregory
Scott Herndon
James McCutchan
Seth Veitzer
Matthew Wheeler

1998-1999

David Bailey
Bradley Baker
Rebecca Bendick
James Boulter
Alison Grimsdell
Paula Hudson
John Miller
Dev Niyogi

1999-2000

Wendy Anderson
Thomas Custer
Alison Fisher
Steven Jacobsen
Sara Martinez-Alonso
Sean Swenson
Kristy Tiampo
Kevin Wilson

1999-2000

Jason Box
Sara Fletcher
Karl Froyd
Hersh Gilbert
Sujay Kaushal
Brian Lerner

Appendices - Undergraduate Research Opportunities Program (UROP)

The Undergraduate Research Opportunities Program (UROP) was designed to create research partnerships between faculty and undergraduate students. "Research" in this context is interpreted as any scholarly or creative activity ranging from traditional scientific experimentation to the creation of new artistic works. UROP awards stipends and/or expense allowances to students who undertake an investigative or creative project in collaboration with a faculty member. Although projects are normally designed around some aspect of the faculty sponsor's research, they may also develop from original ideas of the student, which are endorsed by a faculty sponsor. Whether the context is scholarly or artistic, UROP projects call for significant input on the part of the faculty sponsor.

Year	Name	Affiliation	Research Mentor	Project Title
2001	Limnology	CIRES	Lewis, William	Mechanisms for Displacement of Native Greenback Cutthroat Trout by Non-native Brook Trout in Montane Streams in Colorado
	Limnology	CIRES	Lewis, William	Mechanisms for Displacement of Native Greenback Cutthroat Trout by Non-native Brook Trout in Montane Streams in Colorado
	Limnology	CIRES	Lewis, William	Mechanisms for Displacement of Native Greenback Cutthroat Trout by Non-native Brook Trout in Montane Streams in Colorado
	Limnology	CIRES	Lewis, William	Mechanisms for Displacement of Native Greenback Cutthroat Trout by Non-native Brook Trout in Montane Streams in Colorado
2000	Constance, Andrea	CHEM	Sievers, Bob	CO2 Assisted Nebulization
	Covino, Timothy	EPOB	Lewis, William	Investigation of Microbial Use of Dissolved Organic Nitrogen: Evidence from Aminopeptidase Activity
	Dudon, Gretchen	CIRES	Lewis, William	Growth and Body Condition of Native Cutthroat and Non-nature Brook Trout
	Kawamoto, Janelle	CHEM	Sievers, Bob	Formation of Fine Aerosol Particles Assisted by Supercritical Carbon Dioxide
	Muffly, Matt	EPOB	Lewis, William	Investigation of the Ecological Significance of Dissolved Organic Nitrogen to Heterotrophic Microbial Communities in Streams
	Nikrad, Mrinalini	CIRES	Lewis, William	Examination of the Chemical and Biological Reactivity of Dissolved Organic Nitrogen in Streams

Year	Name	Affiliation	Research Mentor	Project Title
1999	Claiborne, David	GEOL	Goetz, Alexander	Landsat 7 Study
	Courtney, Robert	GEOL	Goetz, Alexander	Landsat 7 Study/Study of Front Range Swelling Soils
	DenOtter, Jason	GEOL	Sheehan, Anne	Crust and Mantle Imaging beneath the Rocky Mountains
	Hogan, Daniel	GEOL	Bilham, Roger	Testing/Installing of a Pair of Long Tiltmeters in Mexico
	Matiasek, Michael	CHEM	Fall, Ray	Investigation of the Mechanism of Acetone and Butanone Production in Pseudomonas
	Matiasek, Michael	CHEM	Fall, Ray	Investigation into the Mechanism of Production of Keto-acids in P. fluorescence and P. putida
	Pietsch, Nick	GEOL	Spetzler, Hartmut	Effects of Pore Geometry and Contaminants on the Seismic Wave Attenuation in Partially Saturated Rocks
	Slaughter, Preston	GEOL	Bilham, Roger	Testing/Installing of a Pair of Long Tiltmeters in Mexico
	Springer, Jayme	CHEM	Copley, Shelley	The Biodegradation of Pentachlorophenol in Sphingomonas Chlorapherolisca
	Wilson, Cara	GEOL	Goetz, Alexander	Conversion of Paper Soils Maps
1998	Cook, Scott	GEOL	Sheehan, Anne	Analysis of Archean/Proterozoic Lithospheric Difference across the Cheyenne Suture
	Friedman, Rachel	CIRES	Parks, Bradley	Coastal hazards in the Laurentian Great Lakes of North America
	Klaus, Joshua	CIRES	Parks, Bradley	Integrating GIS and Environmental Modeling: Problems, Prospects, and Needs for Research
	Korn, David	CIRES	Parks, Bradley	Coastal hazards in the Laurentian Great Lakes of North America
	Leicht, Laura	PHYS	Ritzwoller, Michael	New Estimation for the Centroid Moment Tensor
	Maes, Daniel	CIRES	Parks, Bradley	Integrating GIS and Environmental Modeling: Problems, Prospects, and Needs for Research
	Mallory, Anne	EPOB	Lewis, William	Regulation of Dissolved Inorganic and Organic Nitrogen Delivery to Streams in Summit County
	Nemser, Eliza	CIRES	Parks, Bradley	Coastal hazards in the Laurentian Great Lakes of North America
	Sherry, Jennifer	CIRES	Parks, Bradley	Integrating GIS and Environmental Modeling: Problems, Prospects, and Needs for Research
	Williams, Kevin	PHYS	Ritzwoller, Michael	Incorporation of Second Order Effects of the Coriolis Effect in the Study of Normal Mode Seismology
1997	Cody, Kevin	EPOB	Wessman, Carol	Vegetation Change and Carbon Cycling in Savannas
	Horansky, Robert	CHEM	Vaida, Veronica	Pressure and Temperature Dependent Absorption Cross-sections of Atmospherically Important Molecules
	Minger, Timothy	CHEM	Copley, Shelley	Analysis of Substrate Specificity and Induction of PCP Hydroxylase
	Schiehser, Michael	EPOB	Lewis, William	The Effects of Macrophytes and Herbivorous Crayfish on Methane Flux

Appendices - Summer Minority Access to Research Training (SMART) Program

The University of Colorado at Boulder offers 10-week summer research internships through the Summer Multicultural Access to Research Training (SMART) program. The SMART program, intended for undergraduate students who are interested in preparing for graduate degrees in science, math, and engineering, offers 25 outstanding students the opportunity to conduct research under the guidance of a faculty mentor. SMART interns also participate in workshops designed to enhance their research experience and strengthen their preparation for graduate school.

Year	Name	Affiliation	Research Mentor	Project Title
2001	Koslow, Melinda	CIRES/PAOS	Amanda Lynch	The Climatology of Cyclonic Behavior near Barrow, AK
2000	Datulayata, Pauline	Aeronomy	Leslie Hartten	Examining the Average Daily Cycle of Winds over Galapagos Islands
	Pitter, Shanna	NSIDC	Anne Nolin	Assessment of Snow Characterization in General Circulation Models
1999	Lopez, Nestor	NSIDC	Tingjun Zhang	Archimidian Spiral Rectennas

Appendices - Significant Opportunities in Atmospheric Research and Science (SOARS) Program

SOARS is a model learning community and mentoring program for promoting racial and gender equity in the atmospheric and related sciences. Created by and administered through the National Center for Atmospheric Research, CIRES has formed a partnership with this program to participate in this highly regarded program while providing NCAR with a wider range of disciplines to place students. It is a multi-summer, four year undergraduate and graduate program for students majoring in an atmospheric science or a related field such as biology, chemistry, computer science, earth science, engineering, environmental science, mathematics, meteorology, oceanography, physics, or social science.

Year	Name	Affiliation	Research Mentor	Project Title
2001	Muñoz-Acevedo, Ernesto	Aeronomy	Hartten, Leslie	The Daily Cycle of Low Level Winds over the Island of Nauru in the Equatorial Western Pacific
	Pitter, Shanna	NSIDC	Nolin, Anne	Improving Western United States' Snow Water Equivalent (SWE) Estimates from Passive Microwave Sensors
	Rodriguez, Yasmin	Chemistry	Fall, Ray	Isoprene-producing Bacteria in the Rhizosphere
2000	Green, Kevin	Biology	Lewis, Bill; McGrath, Claire	Relationship between Streambed Mobility and Invertebrate Abundance in Mountain Streams
	Reed, Aisha	CDC	Liebmann, Brant	Diagnosing and Predicting Extreme Precipitation Events in Southeast Brazil
	Pérez-Suárez, Sharon	ETL	Bates, John	Studies of the Variability of Upper Tropospheric Humidity over Space and Time using Geostationary Data
1999	Rodriguez, Ismael	Geology	Goetz, Alex	Surveying Satellite Imagery of the United States' High Plains Aquifer
1998	Naressa Cofield	NCAR/ESIG	Roger Pielke, Jr.,	The Relationship between Precipitation and Flood Damage

Appendices - Invited Interdisciplinary Lecture Series

CIRES is seeking to promote its connections with University departments and NOAA labs by helping to sponsor truly global thinkers that might not otherwise be considered. The intent is to bring in distinguished speakers with perspectives that cross disciplinary boundaries with the hope of establishing enduring new connections after their departure. The following is a list of scientists and academicians invited to date.

Cort Wilmott, Professor of Geography at the University of Delaware on **Spatially Interpolating and Mapping Climate Fields from Lousy Weather-Station Networks** (co-sponsored by the Geography Department).

Joyce Penner, Department of Atmospheric, Oceanic and Space Sciences, University of Michigan on **Climate Change and Radiative Forcing by Anthropogenic Aerosols: A Summary of Current Understanding** (co-sponsored by the Program in Atmospheric and Oceanic Sciences and the Climate Diagnostics Center).

Roger Pielke Jr. of the National Center for Atmospheric Research, Environmental and Societal Impacts Group on **Seasonal Climate Forecasts: Opportunities for and Obstacles to Use in Decision Making** (co-sponsored by Program in Atmospheric and Oceanic Sciences).

David Anderson, head of the Seasonal Forecast Team, European Centre for Medium-Range Weather Forecasts on **Seasonal Forecasting at the ECMWF** (co-sponsored by Program in Atmospheric and Oceanic Sciences and the Climate Diagnostics Center).

Jim Rustad (W.R. Wiley Environmental Molecular Science Laboratory Pacific Northwest National Laboratory) on **Molecular Simulation of Chemistry at Complex Mineral-Water Interfaces** (co-sponsored by the Geology Department).

Roger G. Kennedy, previously Director of the U.S. National Park Service, Director of the National Museum of American History at the Smithsonian Institution, and Vice President of the Ford Foundation, on **The Abrasion of Human and Natural Systems: Fire, Flood, Risk, and Responsibility** (co-sponsored by CIRES Science and Technology Policy Research center).

Appendices - Innovative Research Program Awards

This program is designed to stimulate a creative research environment and encourage synergy between disciplines within CIRES. The intent is to provide an uncomplicated mechanism for supporting small research efforts that can quickly provide concept viability or rule out further consideration. This program encourages novel, unconventional and/or fundamental research that might otherwise be difficult to fund. Proposals should be inventive, might be opportunistic, and need not have an immediate practical application or guarantee of success.

June 1999 Recipients

John Wahr (CIRES), Chris Milly (GFDL) and a graduate student

Satellite Gravity And Large-Scale Hydrology where they are developing techniques for determining continental water and snow cover using satellite gravity field measurements obtained from the GRACE satellite.

Lang Farmer (Geology), Steven George (Chemistry) and Emily Verplanck (Geology)

Development Of Novel Si-Gel Based Ion Sources For Thermal Ionization Mass Spectrometers to improve sample ionization and sensitivity thus enabling isotopic studies on much smaller geologic samples.

John Birks (Chemistry) and a graduate student

Single Molecule Detection In The Gas Phase: An Explosive Idea where they are developing a new analytical technique for quantifying OH, H_2, and DMS.

Ray Fall, Veronica Bierbaum and Thomas Custer (Chemistry)

Selective Detection Of Reactive Biogenic VOCs By Negative-Ion CIMS where they are developing analytical techniques to seek unequivocal identification of recently discovered volatile organic hydrocarbons.

Robert Sievers, Brenda Korte and a graduate student (Chemistry)

Fine Particle Formation Using Supercritical CO_2-Assisted Aerosolization where they are conducting fundamental studies to characterize current technology and improve their techniques.

Bruce Kindel and Zheng Qu (CSES)

High Resolution Solar Radiometer Measurements For The Characterization Of Atmospheric Aerosols And Gaseous Transmission to elucidate the impacts of atmospheric aerosols, develop instrumentation, and conduct field cross-calibrations.

December 1999 Recipients

Ben Balsley and Rod Frehlich (CIRES)

Examining The Relationship Between The Fair-Weather Atmospheric Electric Field And Global Climate Change where they are using kites platforms to obtain continuous FWAEF measurements as a proxy for climate change and an understanding of continual recharging of the planetary electric field.

Shelley Copley (CIRES) and Veronica Vaida (Chemistry)

Chemical Reactivity In Organic Aerosols to determine if interesting chemical reactions occur within organic surfaces of aqueous aerosols as a consequence of their architecture.

Shari Fox (NSIDC)

Inuit Knowledge Of Climate And Climate Change In The Eastern Canadian Arctic; Linking Indigenous And Scientific Knowledge: An Interactive CD-ROM to record the climate history stored in the cultures of indigenous peoples before it is lost.

William Lewis & Sujay Kaushal (CIRES)

A New Method For Estimating Bacterial Growth Rates By Use Of Stable Isotopes Of Carbon And Nitrogen where they are testing a new method of using organic tracers for measuring growth rates in natural microbial communities of aquatic environments.

John Rundle (C4) Claudio Cioffi (Political Science)

Exploring Nonlinear Dynamics Of Extreme Events In Driven Threshold Systems where they are exploring new approaches to modeling nonlinear dynamics of extreme events to derive fundamental results applicable to both geophysical and social systems.

Britt Stephens with Pieter Tans (CMDL)

Development Of A Differential Fuel Cell Analyzer For Tall Tower Atmospheric Oxygen Measurements to improve a commercial O_2 analyzer for investigating O_2:CO_2 signatures and fluxes.

Holger Voemel (CMDL)

Surface Ozone Measurements At San Cristobal, Galapagos Operated By The National Park Youth Group where he is seeking to extend O_3 observations in the Galapagos and involve local youth in this science project.

Chris Williams (AL)

The Sound Of Raindrops: Development Of An Acoustic Rain Gauge to develop a new acoustic technique for the measurement of raindrop size and intensity.

June 2000 Recipients

Don Anderson (ETL) with Marty Hoerling (CDC)

Air Quality Regulations And Snow Accumulation In The West where they will be testing the hypothesis that coal burning and atmospheric haze in the Interior West are correlated with snow accumulation during the preceding season.

Susan Avery, Mike Jensen, Ben Balsley and Rod Frehlich (CIRES)

In Situ Calibrations Of Lower-Atmospheric Horizontal And Vertical Winds And CN_2 Measured By Wind Profilers using a new powered parachute to calibrate profiler radar patterns and thus improve the accuracy and interpretation of 3D wind data.

Tom Chase, Ben Herman (U of AZ) and Roger Pielke, Sr. (CSU)

Mid-Tropospheric Temperature Regulation At High Latitudes where they will test the hypothesis that Arctic air masses maintain enough contact with sea surfaces in winter such that minimum annual SST's are able to control mid-tropospheric temperatures above a certain threshold.

Shelley Copley and Norm Pace (MCDB)

Toward A Molecular Phylogeny Of A Metabolic Enzyme, Maleylacetoacetate Isomerase where they will conduct a phylogenetic analysis of a specific metabolic enzyme to address the distribution of this metabolic pathway among microorganisms.

Daniel King and James Butler (CMDL)

In-Situ Investigation Of Tomato Plants As Methyl Halide Sources where they are studying a homogeneous plant source as a proof of concept for future studies seeking to balance global methyl halide sources and sinks.

Brian Mapes (CDC)

Quantitative Test Of A Statistical-Mechanics Analogy Between Convective Clouds And Chemical Kinetics who is seeking to improve convective updraft area (sigma) in model parameterization of global cloud cover.

Sergey Sokratov and Richard Armstrong (NSIDC)

Simplifying The Representation Of Snow Physics In Environmental Models where they are applying sensitivity testing of various parameters to find the minimum suite of variables for predicting water content of snow cover.

April 2001 Recipients

John Bergman and Prashant Sardeshmukh (CDC)

Climate Modeling with Simplified Dynamics and Detailed Physics where John and Prashant will be testing viability of an intermediate complexity model that will be easier to interpret, have a better statistical footing, and be useful in detecting/predicting long term climate change.

Tom Chase, Vijay Gupta and Keith Nordstrom (CSES)

Developing an Interface Between Simple and Complex Climate System Models for Investigating Geophysiology where they are coupling a simple biospheric/hydrologic model with GCMs as a means for identifying negative feedbacks that are not yet included in current parameterizations.

Martyn Clark (NSIDC) with Lauren Hay and George Leavesley (USGS)

The Use of Multi-Model Super-Ensemble Techniques in Hydrology where they are adapting proven meteorogoical ensemble techniques to a hydrology model to assess improvement of runoff, understand variations, apply regression improvement, and combine with atmospheric ensemble model output.

Gil Compo, Jeff Whitaker and Prashant Sardeshmukh (CDC)

Feasibility of Reanalysis before the Radiosonde Era where they are testing the validity of surface and lower tropospheric circulation reanalyses simulated from previous surface synoptic data as a means of extending climate studies back to the early 1900's.

Dale Hurst and Jim Elkins (CMDL)

Inaugural Survey of Russian And Chinese Emissions of Ozone-Depleting Substances from In-Situ Measurements Aboard the Trans-Siberian Railway where Dale and Jim will be participating in a rare opportunity to measure CFCs in a remote part of Siberia and test progress toward meeting Montreal Protocol standards.

Dan Kowal and Mark McCaffrey (NGDC)

The Climate Time Line Information Tool where Dan and Mark are developing a Web tool to provide user-friendly access to interdisciplinary data that includes a map locator, temporal and spatial displays, statistical assessment tools, and tutorial.

Russ Monson (EPOB) and James Roberts (AL)

The Uptake of Nitrogen Oxides By Plants - Probing the Biological and Chemical Mechanisms where Russ and Jim are linking biological and atmospheric processes by studying peroxyacetyl nitrate radical equilibria and uptake by vegetation.

Louisa Nance (ETL) and Eric Thaler (NWS)

A Study of Anomalous Propagation Signatures in WSR-88D Data During Downslope Windstorms where Louisa and Eric are testing the hypothesis that unexplained Nexrad Doppler echoes reveal terrain-induced gravity waves and may help in predicting destructive downslope winds.

Anne Sheehan and Fred Blume (Geology)

Quantifying Seismic Hazard in the Southern Rocky Mountains through GPS Measurements of Crustal Deformation where Anne and Fred will investigate the seismic stability of the Front Range, take benchmark measurements, and begin recording crustal strain for the first time.

Veronica Vaida (Chemistry) with Shelley Copley (MCDB), Dan Cziczo, Dan Murphy and Adrien Tuck (AL)

Role of Meteoritic Transition Metals in Determining the Chemical and Optical Properties of Atmospheric Aerosols where they are investigating aerosol coagulation and meteoric metal catalysis of organic materials that could have an impact on origin of life theories.

Wanli Wu and Amanda Lynch (PAOS)

An Interdisciplinary Investigation of Uncertainties in the Variability of the Climate and Terrestrial Ecology where Wanli and Amanda are conducting ensemble model simulations to evaluate variability of regional climate and terrestrial ecology uncertainties arising from boundary forcing plus testing if future surface energy partitioning could be expected to change.

Appendices - Honors and Awards - 2000

Barry, Roger G.
Fulbright Fellowship, Moscow State University, Moscow, Russia.

Bilham, Roger G.
University of Colorado - Boulder Faculty Fellowship Award.
Guggenheim Fellowship.

Birks, John W.
Hazel Barnes Award, University of Colorado.

Church, Lee I.
Certificate of Appreciation for Safety support from MASC, NOAA Safety Committee.

David, Donald
CIRES Outstanding Performance Award.

Dichtl, Rudolph J.
Award for Service in Antarctica from the United States Department of Navy for scientific achievement under the U.S. Antarctic Research Program.

Fall, R. Ray
University of Colorado – Boulder Faculty Fellowship Award.

Fetterer, Florence M.
Award of Merit in the Online Competition of the Rocky Mountain Chapter of the Society for Technical Communication.

Hurst, Dale F.
CIRES Members' Council Award of Excellence.

Frehlich, Rod.
Received the 2001 Editor's Award from AMS for the Journal of Applied Meteorology.

Moore, Fred L.
CIRES Members' Council Award of Excellence.

Pyles, Rex D.
Outstanding Student Presentation American Meteorological Society 24th Conference on Agricultural and Forest Meteorology.

Ray, Eric A.
CIRES Members' Council Award of Excellence.

Rundle, John B.
Distinguished Visiting Scientist, Jet Propulsion Laboratory.

Scott, Michon M.

Science Magazine HOT PICKS selection for “Follow a Fossil” web site.
Golden Brain Award for the year 2000 by the Department of Earth and Space Sciences at the Denver Museum of Nature and Science.

Sievers, Robert E.

Art Revue Magazine Award from Foothills Gallery.

Solomon, Susan

Awarded the Bonfils-Stanton Foundation award in the area of Science & Medicine.
Awarded the National Medal of Science by President Clinton.

Tiampo, Kristy F.

Appointed to AGU Committee for Nonlinear Geophysics.

Tolbert, Margaret A.

Outstanding Paper Award for Spring AGU, with student Tara Fortin
Outstanding Paper Award for Spring AGU, with student David Glandorf

Tyus, Harold

Awarded the rank of Fisheries Professional Emeritus by the American Fisheries Society.
Awarded the rank of Emeritus Fellow by the American Institute of Fisheries Research Biologists.

Weickmann, Ann M.

CIRES Members' Council Award of Excellence.

Welsh, Robin J.

Received "Award of Merit" for the "Arctic Climatology Project from Society of Technical Communicators.

Wessman, Carol A.

Fulbright Senior Scholar Fellowship Award.

Westwater, Edward R.

A paper was awarded the Dr. Vilho Vaisala Award by the WMO.

Zhang, Tingjun

Science Magazine HOT PICKS selection for “State of the Cryosphere”(SOTC) homepage at the National Snow and Ice Data Center on permafrost related information .

Zhao, Conglong L.

Who's Who in Science and Engineering, 5th Edition.

Appendices - Community Service and Outreach - 2000

Andrews, Elisabeth J.

Mentoring of 2 graduate students from CU's School of Education Science fair project. Mentor for student from Centennial High School. E-mail mentor to student at Fairview High School.

Araujo-Pradere, Eduardo A.

Boulder County "I have a Dream" Foundation: Speaker at the Career Day at NOAA-SEC

Arge, Charles N.

Served as a judge at the Nederland Junior High School science fair.

Armstrong, Richard L.

Information Liaison to NASA EODIS, approx. 3-6 data/information requests per week on various aspects of snow, ice, avalanche, mountain weather, remote sensing etc. topics.

Auerbach, Nancy A.

Worked with community leaders of Eldorado Springs, CO. investigating the use of GIS to provide a community map for the town web site.
Assisted with html programming to provide other input to the town web site.

Avery, Susan K.

Natural Hazards and Applications Information Center.
CU in Residence Frontiers in Science Program.
Women in Mathematics and Science Conference, Millersville University.

Barrett, Andrew P.

Briefed water managers from Gunnison River District on NSIDC-CIRES and USGS work to improve short-term hydrologic forecasts.

Bergman, John W.

Science fair judge for Martin Park Elementary School, Boulder, CO.
Math e-mentor for 4th grade students at Nederland Elementary School, Nederland, CO. NOAA's Science Fair: Presented two talks on what makes it snow in Boulder and manned a demonstration booth.

Bilham, Roger G.

IMAX movie of Kilimanjaro.
Red Cross movie of disaster preparedness.
Royal Geographic Society talk on Mt. Everest.
Talk on Himalayan earthquakes to Imperial College London.
Plenary session on Urban Seismic Hazard, Puerto Rico.
Talk on Himalayan Geodesy to Survey Dept. Kathmandu.
Talk on Tibet Collisional process to University of Aukland, New Zealand.
Talk on Indian earthquakes to University College London, London, England.
Talk on Indian earthquakes to Oxford University, London, England.
Talk on Collisional processes to University of Leeds, London England,

Birks, John W.
Nuclear Age course, “Nuclear Winter,”.

Boehm, Anita
Part-time chaperon for Ocean Journey field trip.
Assisted with CU Museum Teacher’s Night and Ocean Bowl events.

Brock, Charles
Science/Mathematics tutor and classroom assistant, Crest View Elementary School, Boulder, CO.

Cheshire, Laura
Volunteered for the American Institute of Graphic Arts, Denver Chapter.

Chilson, Phillip L.
Presentation at Louisville Elementary School, Louisville, CO., about the atmosphere on Earth and other planets in our solar system.

Codrescu, Mihail
NOAA Science Festival presenter.
Served as a facilitator/organizer for the Space Weather Week.

Copley, Shelley
Judge, Summit Middle School Science Fair.
Organized Trick-or-Treat for UNICEF Drive.

Cornwall, Christopher
Volunteer facilitator for Boulder County Health Department OASOS (Out And Supporting Our Selves) youth group.

Dichtl, Rudolph J.
Outstanding Boulder Public Library Volunteer.

Ennis, Christine A.
Writer and editor of the Aeronomy Laboratory's quarterly newsletter.
Hosted a field trip for a kindergarten class of Niwot Elementary School, Niwot, CO., to learn about farm animals at a neighbor's farm.

Fetterer, Florence M.
Assisted NOAA NESDIS PR contact Pat Viets on newsworthy events. Examples are the release of the EWG Atlases, MODIS snow products, publication of high profile papers involving NSIDC (e.g. "Observational Evidence of Recent Change in the Northern High-Latitude Environment," in Climate Change, and "Historical Trends in Lake and River Ice Cover in the Northern Hemisphere", in Science).
Volunteer in Colorado's Big Brothers Big Sisters program.

Frost, Gregory J.
Board member for the Commerce Children’s Center, a child-care facility on the Department of Commerce Boulder campus.

Fuller-Rowell, Timothy J.
Participated in Space Weather Panel at the "CU Conference for World Affairs", Boulder, CO.
Science Fair Judge Mapleton Elementary School, Boulder, CO.

Gilles, Mary K.
Worked with Fairview High School, Boulder, CO. with their writing program.

Goetz, Alex F. H.
Judge for Colorado Space Grant Consortium Undergraduate Space Research symposium.

Hare, Jeffrey E.
Science advisor to the Wyoming-2000 Expedition.

Hartten, Leslie M.
Member of the Max Eaton Award Selection Committee for the 24th AMS Conference on Hurricanes and Tropical Meteorology

Johnson, Eric L.
Participated in The Colorado State University Cooperative Extension Precision Farming Conference.
Assisted in the creation of imagery and graphics for David Wager's presentation to the Governor's conference on the benefits of precision farming data and implements.

Jones, Craig H.
Geophysical Examination of Nederland Cemetery, Nederland, CO.

Joy, Craig L.
Charter Representative for Boy Scout Troop 548 in Longmont, CO.

King, Daniel B.
Science judge for National Ocean Science Bowl (Colorado regional competition).
Volunteer at NOAA Science Festival.

Kitzis, Duane R.
Rocky Mountain National Park technical rescue volunteer.

Laursen, Sandra
Developed an interactive exhibit for the NOAA Science Festival presented to Boulder County middle school students and teachers and to the general public.

Lestak, Leanne R.
Taught a 3 hour hands-on GIS and computer cartography module at the Wild Bear Science School, Nederland, CO.

Lewis, William M.
Member - State of Colorado Dept. of Public Health and Environment Mixing Zone Technical Working Group.
Member - State of Colorado Dept. of Public Health and Environment Water Quality Monitoring Advisory Committee.

Lynch, Amanda H.

Chair, Gustavson Memorial Endowment Committee.
CIRES Distinguished Lectureship Convener.

Machol, Janet L.

Science fair judge and tutored an elementary school student at Summit Middle School, Louisville, CO.

Marquis, Melinda C.

Member of the Boulder Valley School District Scientific Review Board.
Regional science fair judge at Summit Middle School Science Fair, Louisville, CO.

McCaffrey, Mark S.

Volunteer with the Boulder Area Sustainability Information Network (BASIN) and the Boulder Community Network (BCN).
Acting President of the Boulder Creek Watershed Initiative.

McKeen, Stuart A.

Assisted with NOAA 26 year Anniversary Presentation and Display.

McLean, Bradley T.

Volunteer at Colorado's Ocean Journey as a journey guide.

M**orrison, Glenn C.**

Worked with Fairview High School, Boulder, CO., teachers to develop and perform experiments for students in the International Baccalaureate Program.

Nishiyama, Randall T.

Member of the Archaeological Institute of America.

Parks, Bradley

Participated in various field trips for Nederland Middle and High School, Nederland, CO.

Persson, Ola P. G.

Gave presentation on the Arctic Ocean to first graders at Flatirons Elementary School, Boulder, CO.

Romashkin, Pavel A.

Donated educational software to Mead Elementary School, Mead, CO.

Scambos, Ted A.

Presentations at local Elementary School: "The Chemical Elements".
Numerous radio, TV, newspaper interviews on Antarctica and Global Change.

Serreze, Mark

Media contact for issues related to Arctic climate change Science fair judge, Martin Park Elementary School, Boulder, CO.

Sheehan, Anne F.

State of Colorado Earthquake Hazard Subcommittee Member.
Lecture on Colorado earthquakes to Denver Chapter, Association of Women Geoscientists.

Sheffield, Elizabeth M.

Work part-time at WOW! – World of Wonder Children's Museum, which caters to children aged 15 months to 11 years.

Sievers, Robert E.

Member - Governor Owen's Biotechnology Task Force
Member - Board of Directors, Arts and Humanities Assembly of Boulder
Member - Board of Directors, Norwest Bank

Sigren, Beth A.

Volunteer for Boulder Community Network

Smith, Lesley K.

Member of the Technical Advisory Panel for the National Ocean Science Bowl.
Judge for the National Ocean Science Bowl.
Scientific mentor to a local Denver high school teacher who is implementing inquiry-based field work at Rocky Mountain Arsenal.
Scientific advisor for Integrated Earth exhibit designed by Space Science Institute. Guided a number of at-risk high school student groups in half-day field trips to Boulder Creek.
Taught a unit on magnetism and electricity for the kindergarten class at Jarrow Montessori School, Boulder, CO.

Sperry, Paul D.

Ocean Bowl team leader.
Science fair judge.
Mentor for a developmentally disabled adult building a career at NCAR.
Volunteer for the Mary Sandoe House assisted care living center.
Helping Boulder Mayor on environmental initiative.

Spetzler, Hartmut A.

Colorado High Schools and Middle Schools meet to analyze how science teaching can be improved.
New course development for future teachers, observations of teaching in rural Colorado schools.

Stevermer, Amy J.

Coordinated two hands-on science demonstrations for a Girls in Science program.

Straub, Katherine H.

Judge for the Boulder Valley Regional Secondary Science Fair.

Thomson, David

Aeronomy Lab and CIRES representative to the Transportation Alternatives Committee of the Department of Commerce Labs.

Thrasher Hybl, Tracy L.

Served as the NASA USWG outreach lead.

Tiampo, Kristy F.

Science tutoring and lectures volunteer, Grade 8 Casey Middle School, Boulder, CO.

Tyus, Harold

Presentation at the Stream Corridor Restoration Workshop, sponsored by the USEPA. Served as a naturalist and interpreter for two river trips sponsored by Colorado's Ocean Journey, Denver, CO.

Vaida, Veronica

Lectured on Thermochemistry and Spectroscopy, Boulder High School, Boulder, CO.

Verplanck, Emily P.

Science Fair Judge, Crest View Elementary School, Boulder, CO.
Classroom Assistant, Crest View Elementary School, Boulder, CO.
Girl Scout Leader, Troop #1609, Boulder, CO.

Virden,William T.

Participated in the Fall Science Festival at the David Skaggs Research Center.

Voemel, Holger W.

Atmospheric science workshop for kids in Galapagos.

Walloch, Lynn R.

Marketing Committee, CU Federal Credit.

Weaver, Ronald

Presentation to the Greeley Senior Kiwanis Club on Global Monitoring using Remote Sensing Satellites.

Weil, Jeffrey

Assistant Scoutmaster, Troop 78, Boy Scouts of America.
Volunteer, Share-A-Gift Program.

White, Allen B.

Volunteer, St. John's Episcopal Church.

Wolter, Klaus

Volunteer to Colorado Drought (and Flood) Task Force.
Three articles in Boulder Daily Camera, Newspaper related to regional climate and its impact on Colorado.

Young, Doug J.

Volunteer on the Westminster Transportation Commission as the Vice Chairman

Appendices - Journal Publications by CIRES Scientists

January – December 2000

Aarons, **B. L.**, **M. Mendillo**, **K. L.**, **M. Codrescu**. Global Positioning System phase fluctuations and ultraviolet images from the Polar satellite. **Journal of Physical Chemistry, 105**, 5201-5213. 2000.

Acton, **D.**, **A. Tessema**, **M. Jackson**, **R.G. Bilham**. The tectonic and geomagnetic significance of paleomagnetic observations from volcanic rocks from Afar, Africa, Earthquake. **Planetary Science Letters, 180**, 225-242. 2000.

Aleinikoff, **J.N.**, **G.L. Farmer**, **R.O. Rye**, **W.J. Nokelberg**. Isotopic evidence for the sources of cretaceous and tertiary granitic rocks, east-central alaska: implications for the tectonic evolution of the Yukon-Tanana terrane. **Canadian Journal of Earth Science, 37**, 945-956. 2000.

Alexander, **M.A.**, **J.D. Scott**, **C. Deser**. Processes that influence sea surface temperature and ocean mixed layer depth variability in a coupled model. **Applied Optics, 105**, 823-842. 2000.

Ambraseys, **N.**, **R.G. Bilham**. A note on the Kandra Ms=7.8 earthquake of 4 April 1905. **Current Science, 79**, 101-106. 2000.

Anadarajah, **K.**, **P.M. Kiefer**, **B.S. Donohoe**, **S.D. Copley**. Recruitment of a double bond isomerase to serve as a reductive dehalogenase during biodegradation of pentachlorophenol. **Biochemistry, 39**, 5303-5311. 2000.

Andrews, **E.**, **P. Saxena**, **S. Musarra**, **L.M.Hildemann**, **P. Koutrakis**, **P.H.McMurry**, **I. Olmez**, **W.H.White**. Concentration and composition of atmospheric aerosol from the 1995 SEAVS experiment and a review of the closure between chemical and gravimetric measurements. **IEEE Trans, Geosci. Remote Sensing. 50,** 648-664. 2000.

Angevine, **W.**, **A. White**. Cloud-topped continental boundary layer structure and behavior. **International Association of Hydrological Sciences,** 192-195. 2000.

Angevine, **W.**, **A. White**, **C. Senff**, **M. Trainer**, **R. Banta**. Urban heat island observations over Nashville in 1999. **International Association of Hydrological Sciences,** 310-311. 2000.

Anghel, **M.**, **W. Klein**, **C. Ferguson**, **J. Rundle**, **J. Martins**. Statistical analysis of a model for earthquake faults with long-range stress transfer. **International Journal of Modern Physics C**. 2000.

Araujo Pradere, **E.A.**, **T.J. Fuller Rowell** . A model of a perturbed ionosphere using the auroral power as the input. **AGU Geophysical Monograph, 39**, 29-36. 2000.

Araujo Pradere, **E.A.**, **T.J. Fuller Rowell** . A model of a perturbed ionosphere using the auroral power as the input. **Rev Sci Instrum, 39**, 1-. 2000.

Araujo Pradere, **E.A.**, **T.J. Fuller Rowell**, **M.V. Codrescu**. The possibility to model ionospheric perturbed conditions through empirical models. **AGU Geophysical Monograph**. 2000.

Arbetter,**T. E.** Cover photograph: SHEBA ice camp as observed by the NCAR C-130, 8 July 1998. **Journal of the Atmospheric Sciences, 81**. 2000.

Arge, **C. N.**, **V. J. Pizzo**. Improvement in the Prediction of Solar Wind Conditions Using Near-Real Time Solar Magnetic Field Updates. **Atmospheric Environment, 105**, 10465-10479. 2000.

Armstong, **R. L.**, **M. J. Brodzik**. Validation of passive microwave snow algorithms. **Applied Optics,** 1255-1257. 2000.

Asner, **G.P.**, **C.A. Wessman**, **C.A. Bateson**. Impact of tissue, canopy and landscape factors on reflectance variability of arid ecosystems. **Remote Sensing of Environment, 74**, 69-84. 2000.

Asner, **G.P.**, **C.A. Wessman**, **C.A. Bateson**, **J.L. Privette**. Impact of Tissue, Canopy, and Landscape Factors on the Hyperspectral Reflectance Variability of Arid Ecosystems. **Nature, 74**, 69-84. 2000.

Bailey, **D.A.**, **A.H. Lynch**. Development of an Antarctic regional climate system model: Part 1. Sea ice and large-scale circulation. **Journal of Climate, 13**, 1337-1350. 2000.

Bailey, **D.A.**, **A.H. Lynch**. Development of an Antarctic regional climate system model: Part 2. Station validation and surface energy balance. **Journal of Climate, 13**, 1351-1361. 2000.

Barabash, **V.**, **P. B. Chilson**, **S. Kirkwood**. A comparison of PMSE occureence with energetic particle precipitation detected by riometer in Northern Scandinavia. **Nonlinear Processes in Geophysics,** 108-111. 2000.

Barry, **R.G.**, **A. Seimon**. Research for mountain area development: Climate fluctuations in the mountains of the Americas and their significance. **Ambio, 29 (7)**, 364-370. 2000.

Barry, **R.G.**, **M.C. Serreze**. Atmospheric components of the Arctic ocean freshwater balance and their interannual variability. **in E.L. Lewis (ed.), The Freshwater Budget of the Arctic Ocean, Kluewer Acad. Publ.** 45-46. 2000.

Bassatt, **W.A.**, **H.J. Reichmann**, **R.J. Angel**, **H.A. Spetzler**, **J.R. Smyth**. New diamond anvil cell for gigahertz ultrasonic interferometry and x-ray diffraction. **American Mining, 85**, 283-287. 2000.

Bateson, **C.A.**, **G.P. Asner**, **C.A. Wessman**. Endmember bundles: a new approach to incorporating endmember variability into spectral mixture analysis. **Trans. on Geoscience and Remote Sensing, 38(2)**, 1083-1094. 2000.

Bauer, **R.**, **T. Scambos**, **G. Scharfen**. U.S. Antarctic Glaciological Program Data Management. **Polar Geography**. 2000.

Bauer, **R.**, **T. Scambos G. Scharfen**, **M. Eakin**, **D. Anderson**. The Ice Core Data Gateway: Ice Core Data Access Via the World Wide Web. **Journal of Glaciology**. 2000.

Baumann, **K.**, **E.J. Williams**, **W.M. Angevine**, **J.M. Roberts**, **R.B. Norton**, **G.J. Frost**, **F.C. Fehsenfeld**, **S.R. Springston**, **S.B. Bertman**, **B. Hartsell**. Ozone production and transport near Nashville, Tennesse: Results from the 1994 study at New Hendersonville. **Quarterly Journal of the Royal Meteorological Society, 105**, 9137-9153. 2000.

Belmonte, **A.**, **B.J. Rye**. Heterodyne lidar returns in turbulent atmosphere: performance evaluation of simulated systems. **Remote Sensing of Environment, 39**, 2401-2411. 2000.

Bendick, **R.**, **R.G. Bilham**, **J. Freymueller**, **K. Larson**, **G. Yin**. Geodetic evidence for a low slip rate in the Attyn Tagh Fault and constraints on Asian deformation. **Nature, 404**, 69-72. 2000.

Benjamin, **S. G.**, **G. A. Grell**, **J. M. Brown**, **K. J. Brundage**, **D. Devenyi**, **D. Kim**, **B. Schwartz**, **T. G. Smirnova**, **T. L. Smith**, **S. S. Weygandt**. The 20-km version of Rapid Update Cycle. **Technology,** 421-423. 2000.

Bergman, **J.**, **H. Hendon**. Cloud radiative forcing of the low latitude tropospheric circulation. **Journal of Atmospheric and Oceanic Technology, 57**, 2225-2245. 2000.

Bergman, **J.**, **H. Hendon**. The impact of clouds on the seasonal cycle of radiative heating over the Pacific. **Journal of Atmospheric and Oceanic Technology, 57**, 545-566. 2000.

Bilham, **R.G.**, **T-T. Yu**. The morphology of thrust faulting in the 21 September 1999, Chichi, Taiwan earthquake. **Journal of Asian Earth Sciences, 18 (3)**, 1-17. 2000.

Bilham, **R.G.**, **V.K. Gaur**. The geodetic contribution to Indian seismotectonics. **Current Science, 79**, 101-111. 2000.

Blanc, **B. P.**, **J. Wasier**, **D. Juve**, **V.E. Ostashev**. Experimental studies of sound propagation through thermal turbulence near a boundary. **American Meteorological Society Boundary Layers and Turbulence Symposium**, 1-5. 2000.

Bradley, **E.F.**, **C.W. Fairall**, **J.E. Hare**, **A.A. Grachev**. An Old and Improved Bulk Algorithm for Air-Sea Fluxes: COARE2.6A. **Journal of the Acoustical Society of America,** 294-296. 2000.

Breon, **F. M.**, **D.L. Jackson**, **J.J. Bates**. Calibration of the Meteosat water vapor channel using coincident NOAA/HIRS-12 measurements. **Quarterly Journal of the Royal Meteorological Society, 105**, 11925-11933. 2000.

Brock, **C.**, **B. Kaercher**, **A. Petzold**, **R. Busen**, **M. Fiebig**. Ultrafine particle size distributions measured in aircraft exhaust plumes. **Quarterly Journal of the Royal Meteorological Society, 105**, 26555-26567. 2000.

Bromwich, **D.H.**, **J.J. Cassano**, **Z. Guo**, **L. Li**, **K.M. Hines**. Bipolar modeling over ice sheets with MM5. **Quaternary Science Reviews,** 150-153. 2000.

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