SCHOOL OF SCIENCE AND MATHEMATICS

Undergraduate Research Poster Display

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Note: The names of Millersville University faculty advisors are designated by an asterisk (*) in the abstracts.

Biology

1. Antibody Attachment to Nanowire Arrays

Dower, Nicholas J.; Flynn, Clare; Rickard, Lyman; Habib, Youssef and Cosentino, M. James.*
Departments of Biology and Chemistry, Millersville University and Illuminex Corp., Millersville, PA 17551

A new approach in the development of sensors that will detect extremely small concentrations of analytes such as hormones or cancer indicators in blood and other fluids very rapidly, is one that utilizes nanotechnology. In this approach, very small structures such as nanowire arrays need to be coated with active antibodies directed against the compounds to be analyzed. It is the purpose of these experiments to measure the degree of antibody attachment under various conditions. We have previously attached antibodies made against an indicator for ovarian cancer (CA 125) to nanowire arrays provided by Illuminex Corporation. These arrays are groups of parallel wires measuring approximately 80 nanometers by 120 nanometers attached to a glass substrate. Through a series of chemical reactions using MUA (11-mercaptoundecanoic acid) side arms and spacer molecules, the antibodies are covalently attached to the nanowires. In order to find the amount of antibody binding to the arrays, a fluorescein labeled second antibody was incubated with the functionalized wires. This incubation led to an emission of fluorescence. The degree of fluorescence detected is proportional to the amount of antibody attached to the nanowires and was approximately $9x10^{-4}$ ug of antibody per mm^2 of nanowire array. It was the purpose of this study to determine which spacer molecule gave optimal antibody attachment. The spacer molecules tested were 6-mercapto-1-hexanol, 4-mercapto-1-butanol, and 1-octanethiol. Once we found 4-mercapto-1-butanol gave the greatest fluorescence, we attempted the antibody attachment with a variety of MUA to spacer molecule ratios and found no significant difference in the antibody attachment with various amounts of spacer. These studies have led us to establish the optimal conditions for covalent linkage of antibody to nano structures.

2. Changes in Avian Communities Associated with Streamside Restoration

Moore, Wesley; High, Erin (MU 2005); Lituma, Christopher (MU 2005); and Zegers, David A.*
Department of Biology, Millersville University, Millersville, PA 17551

In July of 2004 LandStudies, Inc. conducted a stream/floodplain restoration project (Fox-Zimmerman) on the Hammer Creek in Lancaster County, PA. The project entailed altering the flow regime of the creek channel as well as providing it with an effective floodplain. In 2002 a similar alteration was performed on another portion of the same creek (Snavely Mill). In May 2004 we started a study designed to assess changes in avian species diversity at theses two locations. In May 2005 a third location along a degraded segment of Hammer Creek was added to the study as a control. Our objective was to

document avian community changes during the restoration. At each location a point count census was conducted at 10-20 day intervals from May, 2004 through September, 2006. Four sampling points were established between 10 and 20 meters apart. All birds seen and heard within a 10 meter radius during 10 minutes were recorded. This preliminary report compares species richness and evenness in the avian communities found at these three sites and documents fluctuations in bird activity associated with migration, season, and habitat restoration.

3. The impact of the meadow vole, *Microtus pennsylvanicus*, on the survival of sapling trees in a riparian restoration project: interim report.

Starr, Scott and Zegers, David A. *
Department of Biology, Millersville University, Millersville, PA 17551

We are conducting a study of the effect of the abundance of meadow voles on the survival of sapling trees in meadows undergoing a riparian restoration. The study is being conducted on the Yocom farm in Manor Township, Lancaster County, PA. In May 2005 a randomized block design experiment was initiated that involves six 7.62x7.62 m trapping grids. Each grid contains 21-23 Sherman live traps placed in or adjacent to vole runways. Three grids were surrounded by fencing to exclude meadow voles and three remained unfenced. Each grid area was planted with 16 sapling trees (4 each of white oak, river birch, green ash and sweet gum); each seedling was surrounded by a 0.60m tall plastic tube. After 1½ years live trapping and removal of voles from the exclosure grids produced vole density on those plots significantly lower than that on the control grids. This preliminary report documents the relationship between sapling survival and meadow vole density for the first half of this three-year study.

4. Identification of Genes Involved in Regulating *HOT1*-Stimulated Recombination in *Saccharomyces cerevisiae.*

Sutcliffe, Erin and Hepfer, Carol E.*
Department of Biology, Millersville University, Millersville, PA 17551

Genetic recombination is an essential process occurring in the cells of all living organisms. By enabling the combination of genes in an organism's offspring to differ from the arrangements in their parents, recombination provides opportunities for natural selection. Recombination also maintains the genome by repairing damaged DNA. Deciphering mechanisms and identifying proteins involved in recombination should increase our understanding of cancer and aging. Yeast can be used very effectively as a model to better understand mechanisms of genetic recombination in all eukaryotic organisms. Many processes in yeast are very similar to those in humans, but yeast cells grow more rapidly and their genes can be manipulated more easily. In yeast, the *DEG1* gene is essential for normal growth at elevated temperatures and for high rates of mitotic recombination that maintain repetitive ribosomal DNA sequences. Mutations in *DEG1*

impede cell growth at elevated temperatures and specifically reduce recombination that normally is stimulated by the hotspot known as *HOT1*. Since the product of *DEG1* is a pseudouridyl synthase that modifies transfer RNA, its impact on *HOT1*-stimluated recombination probably results from the altered synthesis of other proteins more directly involved in the process. The goal of this project is to identify some of those proteins and to determine their roles in recombination. If mutations in *DEG1* reduce *HOT1*-stimulated recombination and prevent growth at high temperatures by reducing the activity of certain proteins, then restoring the expression of those proteins should suppress mutant phenotypes. To find genes encoding potential suppressor proteins, temperature sensitive *deg1* cells were transformed with a collection of normal yeast genes carried on vectors that increase their expression. Transformed cells able to grow at high temperatures were then analyzed to identify suppressor genes. Candidate suppressors will be evaluated to determine if they play an important role in genetic recombination.

Chemistry

5. Synthesis and Characterization of Copper Nanowires

Butt, Rebecca L. and Rickard, Lyman H.*
Department of Chemistry, Millersville University, Millersville, PA 17551

The production of copper nanowires using an anodization process is being investigated. Anodized aluminum metal forms an oxide template of nanoscale cylindrical holes. These holes are then filled with copper metal to form nanowires. The oxide template is then etched away in a strong acid bath. The nanowire arrays are then characterized using scanning electron microscopy.

The determination of proper etch time for complete etching of the oxide layer was investigated and found to be nine hours. An effective method of obtaining cross-sectional images of nanowire arrays was also investigated using the scanning electron microscope.

6. Electroroughening of Nanowire Arrays for the Development of a Biosensor

Flynn, Clare M. and Rickard, Lyman H.*
Department of Chemistry, Millersville University, Millersville, PA 17551

This project is part of an investigation to develop a biosensor of the detection of ovarian cancer using nanowire arrays. In order to functionalize gold and silver nanowire arrays the nanowires are cleaned and roughened using electrochemical techniques. Cleaning of

the wire arrays is necessary to remove impurities such as oxalates from the surface of the array in order to facilitate its functionalization. Roughening of the nanowire surface improves the analytical signal obtained. Electrochemical techniques take advantage of a current passed through the nanowire array as the voltage is increased causing oxidation of impurities on the array surface. The gold and silver arrays will be run at several voltage ranges to determine their respective optimal voltages. Scanning electron microscopy will be used to characterize the electroroughened nanowire arrays.

7. Pattern Transfer Using Soft Lithography

Michaylira, Stephen and Mbindyo, Jeremiah K.N.*
Department of Chemistry and Department of Industry and Technology
Millersville University, Millersville, PA 17551

Photolithography is the process used to pattern computer chips. We describe an experiment that demonstrates stamping lithography, a possible alternative to photolithography which does not require expensive equipment.
A stamp was created by curing polydimethylsiloxane (PDMS) on a patterned template and a glass slide coated with silver by electroless chemical deposition. The stamp was then inked with a thiol solution, dried and brought into brief contact with the Ag. Only the raised parts of the stamp made contact, transferring the thiol molecules to the surface. This single layer of molecules was adequate to protect the underlying silver from etching when exposed to potassium ferrocyanide/ferricyanide solution. The areas that were not coated dissolved in the etchant, resulting in a metal pattern that was a replica of the pattern on the stamp.

Computer Science

8. Designing a 3D Graphics Toolkit in C++/Direct3D

Hollinger, Jonathan D., Land, Greg J., Olszewski, Mark A., Payeur, Robert M., Webster, Roger W., and Zoppetti, Gary M.*
Department of Computer Science, Millersville University, Millersville, PA 17551

After one and a half semesters, the MU Graphics and Gaming group has developed a 3D graphics toolkit in C++/Direct3D. Direct3D is Microsoft's 3D graphics application programming interface (API). The MUDirectXToolkit complements the MUOpenGLToolkit, written in C++/OpenGL and currently used in CSCI 375 (Computer Graphics and Virtual Reality) and CSCI 475 (3D Game Programming and Computer

Animation). Students now have the opportunity to learn the two most popular graphics API's.

C++ is an object-oriented language well-suited for graphics and game application development. It enables the creation of classes that encapsulate behavior and state. Additionally, optimizing compilers produce native code that executes quickly. As a testament to the toolkit's efficiency, several models with hundreds of thousands of polygons can be rendered at over 30 frames per second.

We now describe the primary classes in the toolkit. The Moveable class forms the heart of the DirectX toolkit. It performs highly optimized vector, matrix, and quaternion manipulations to provide six degrees-of-freedom movement. Moveable objects raise events that can be received by multiple listeners upon movement; this is implemented using the Boost signal/slots library. The Camera class inherits from Moveable, and enables the specification of an eye point in the 3D world. This eye point can then be bound to Moveable's to follow an object. Light also inherits from Moveable; thus, point lights and spotlights can be mobile. Class Renderable, derived from Moveable, manages multiple 3D Mesh's and allows related objects to be displayed with one call to function "Render". These objects will move in tandem, as, for example, a racecar outfitted with spoilers or wings. Classes derived from Mesh, such as Model3ds, load geometry, material, and lighting data from files. The Model3ds class also supports primitive animation; parts of complex objects can be rotated independently (such as the rotors of a helicopter). A TextureManager class loads and caches 2D images that are mapped to geometry to add detail to models. Since textures can be memory intensive, the TextureManager prevents duplicates from being loaded.

Currently the group is working on enhancing animation and adding physics-based movement.

9. Extending 3D Meteorological Data Visualization in IDV

Mitton, Kenneth T., Clark, Richard D., and Zoppetti, Gary M.*
Department of Computer Science, Millersville University, Millersville, PA 17551

The Integrated Data Viewer (IDV) from Unidata is a Java™-based software framework for analyzing and visualizing geoscience data (http://www.unidata.ucar.edu/software/idv/). It uses an analysis and visualization component called Visualization for Algorithm Development (VISAD), which itself is built upon the Java™ 3D application programming interface.

Although IDV allows users to view 3D datasets, one cannot "step into" the dataset for a more immersive experience; the user is restricted to viewing the atmosphere from outside the data volume. We have extended IDV to allow for an engaging navigation of the atmosphere with six degrees-of-freedom movement, effectively making the user the

weather balloon. Thus the user can probe the eye of a hurricane, for example, move to the probe position with one keystroke, and then sample points of interest while immersed in the storm.

Currently, the user can fly through the dataset, probing points or simply looking for interesting weather phenomena. We will add the functionality to launch sounding balloons from the probe to gather data for plot creation. Additionally, we will enable path logging to record the user's navigational history.

While this research focuses on meteorological data visualization, the extensions we have implemented apply to other domains as well (such as oceanography and solid earth science).

Earth Sciences

10. Garnet Compositions Producing Protective-Surface Coatings Identified Using the Pilling-Bedworth Rule

Anderson, Diane and Price, Jason R.*
Department of Earth Sciences, Millersville University, Millersville, Pa 17551

Garnet compositions that produce a protective-surface coating (PSC) can be determined by applying the Pilling-Bedworth Rule. Application of the Pilling-Bedworth Rule to each of 251 published unique garnet chemical compositions found that only ~23% (11 out of 48) almandine garnet compositions have adequate iron and aluminum stoichiometries to produce a PSC of goethite + gibbsite. The minimum almandine garnet stoichiometries needed to produce a goethite + gibbsite PSC (based on an anion basis of O_{24}) are ~3.5 for iron and ~3.8 for aluminum. Substituting kaolinite for gibbsite lowers the stoichiometries for iron to ~2.2 and aluminum to ~3.6 and increases the almandine garnets producing a PSC to ~88% (42 out of 48).

The chemical compositions of four almandine garnet samples from western North Carolina and one almandine garnet sample from southern Lancaster County, Pennsylvania where obtained. Microscopic observations reveal that the garnets from western North Carolina form PSCs while the southern Lancaster County, Pennsylvania garnet does not. The values obtained by applying the Pilling-Bedworth rule to all five garnets shows that none of them should have produced a PSC of goethite + gibbsite for their respective chemical compositions, while only one of the western North Carolina garnets would not produce a PSC of goethite + kaolinite. Therefore, the likely weathering products for the Lancaster County, Pennsylvania garnets are goethite + gibbsite, while for the North Carolina garnets, goethite + kaolinite are the likely secondary minerals.

These results underscore the importance of proper secondary mineral characterization when applying the Pilling-Bedworth Rule to almandine garnet weathering. Substituting kaolinite for gibbsite demonstrates how changing a secondary mineral can impact the number of garnets producing a PSC. Microscopic confirmation of the presence of a PSC, along with XRD and other microanalytical methods is necessary to support that the proper secondary minerals have been identified.

11. Satellite-Based Studies of Smoke-Cloud Interactions in the Atlantic Ocean off the Coast of South America

Eipper, Daniel[1] and Gasso, Santiago (Research Supervisor)[2]
[1]Department of Earth Science, Millersville University, Millersville, PA 17551
[2]Climate Branch, NASA/Goddard Space Flight Center, Greenbelt, MD 20771

The influence of aerosols on cloud properties is important because aerosols can change cloud radiative properties, cloud lifetimes, and rain patterns. However, observational studies linking aerosol effects to clouds properties have been sparse; in particular there are very few studies focusing on the effects of aerosols downwind of the biomass burning regions of South America.

We analyzed collocated aerosol and cloud parameters derived by the MODIS instrument on the Terra and Aqua satellites and precipitation parameters from the instruments onboard the TRMM satellite. The MODIS parameters used in this study (Level 3 daily) were aerosol optical depth (AOD), cloud optical thickness (COT), cloud effective radius (CER), cloud top pressure (CTP) and cloud fraction (CF). The cumulative rainfall (CR, level 3B42RT) parameter was obtained from TRMM. Data were obtained from the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) interface developed by NASA (http://giovanni.gsfc.nasa.gov/). The data were selected in the South Atlantic Ocean downwind of Southern Brazil for the most active biomass burning months along an axis perpendicular to the coast and at the center of the mean location of the smoke plume—as determined by monthly maps of AODs. We analyzed the variation of COT and CER for low and high clouds (defined by a threshold set at 650 mb) as well as CF and CR along the axis as a function of AOD in monthly and 4-day averages for the years 2001-2005.

We found evidence suggesting a possible influence of smoke on cloud properties. Elevated aerosol concentrations correlated with smaller CER and higher COT. Furthermore, during the most active burning seasons, we observed lower rainfall in low clouds, but higher average rainfall in high clouds. This suggests that high aerosol concentrations may initially suppress rainfall but subsequently invigorate convective clouds and produce more active, higher-precipitation thunderstorms.

This research was conducted through the NASA Summer Institute on Atmospheric, Biospheric, Hydrospheric, and Solar and Space Plasma Sciences (Code 614)

12. Investigation of Geostrophic Adjustment and the Evolution of Anomalous Atmospheric and Oceanic Circulations, using a Shallow-water Model

Eipper, Daniel and DeCaria, Alex*
Department of Earth Science, Millersville University, Millersville, PA 17551

We developed a one-dimensional shallow-water model to simulate the adjustment of a constant density fluid in a rotating reference frame, and applied a modified version of the model to flow fields which occur in the atmosphere and oceans. The model is programmed in the Interactive Data Language (IDL) and uses standard finite-difference techniques. The model includes radiative boundary conditions to allow waves to traverse out of the model domain with minimal reflection. The model correctly simulates the geostrophic adjustment process, resulting in small-scale disturbances adjusting the mass field to the initial velocity field and large-scale disturbances adjusting the velocity field to the initial mass field. The goal is to have an easy-to-use model that can be used in a classroom setting to demonstrate important large-scale adjustment process that occur in the atmosphere and oceans. We also generated a second version of the model, using cylindrical coordinates, to simulate adjustment in axisymmetric circulations. The model accurately initializes and maintains balanced ordinary circulations which commonly occur in the atmosphere and oceans. It also supports balanced anomalous flows that are mathematically possible but rarely observed. Currently, we are exploring the adjustment that takes place when circulations are disturbed from a balanced state, in order to gain insights into the formation and evolution of anomalous circulations.

13. An Evaluation and Comparison of Microphysics Fields in Dennis (2005) at Various Lifecycle Stages

Meyers, Eric[1] and Rogers, Robert, PhD (Mentor)[2]
[1]Department of Earth Sciences, Millersville University, Millersville, PA
[2]Hurricane Research Division, Atlantic Oceanographic and Meteorological Laboratory, Miami, FL

In an effort to improve the representation of microphysics fields in high-resolution tropical cyclone simulations, this research evaluated the statistics of microphysics fields from 1.67-km simulations of Hurricane Dennis (2005) using the MM5 mesoscale model. Simulated microphysics fields were analyzed at two discrete time periods - "early" (18:00Z July 5th – 00:00Z July 6th) and "late" (06:00Z July 7th – 12:00 Z July 7th) - when Dennis intensified from a weak tropical storm to a category 1 hurricane in the observations. Means and distributions were calculated for various microphysical fields including vertical velocity, reflectivity, and ultimately hydrometeor (i.e. graupel, rain, snow) concentrations. At the forefront of these statistical analyses, the use of contoured

frequency by altitude diagrams (CFADs) conveyed the most representative illustration of statistical differences in simulated microphysics fields between the "early" and "late" periods.

These statistical analyses show that the MM5 simulation exhibits a unique microphysical evolution. From the CFADs of vertical velocity (confined to convective regions), it was determined that a small percentage (.1% to .01%) of large updrafts (i.e. isolated convective cores) between 15 m/s and 30 m/s exist during the "early" period; this localized, intense convection is virtually absent (< .01%) during the "late" period of the simulation. Higher mean graupel mixing ratio during the early period (by ~ .5 g/kg) throughout the upper troposphere suggests that isolated convective cores contribute to the majority of the transport of super-cooled liquid droplets above the melting level (~4.5 km). It is hypothesized that an associated temporal variability of latent heat release potentially explains the MM5's deficiency in replicating Dennis's intensification. These differences in microphysics between Dennis's "early" and "late" organization exhibit a temporal trend in the model that will, in future analyses, be statistically compared with observed fields.

14. Geophysical Sources of Infrasound with a Focus on Atmospheric Turbulence

Cipriani, James P.[1] and Alfred J. Bedard (Mentor)[2]
[1]Department of Earth Sciences, Millersville University, Millersville, PA 17551
[2]NOAA Earth Systems Research Laboratory, Boulder, CO 80305

Infrasound is low-frequency sound that is generated by the compression and expansion of waves. It can be detected by microbarographs, which measure small pressure fluctuations in the atmosphere. Many everyday events produce infrasound such as severe storms, earthquakes, volcanoes, meteors, avalanches, and turbulence (flow instability). The purpose of my research was to identify infrasound on three specific dates using time series and background Meteorology: November 30, 2003; January 12, 2004; and January 15/16, 2004. It was possible to use triangulation techniques to locate the infrasound (by using the azimuth time series from three sites comprising the Infrasound Detection Network in Colorado and Kansas). Using the correlation coefficient time series (along with the azimuth time series), it was possible to measure the width (duration in minutes) of the infrasound pulses and identify the source of the infrasound (avalanches, meteors, or turbulence). Avalanches were characterized by short durations with weak winds aloft; meteors were characterized by sharp shifts in azimuth with time; and turbulence events were characterized by long durations with strong winds aloft. On November 30th, all three sources were identified in western Colorado; on January 12th, only avalanches were observed in western and southern Colorado; on January 15/16th, all three sources were observed in western Colorado once again.

15. Lightning Research/Climatology for Southeastern Pennsylvania and Correlation between Lightning Density and Terrain Elevation

Cipriani, James; DeCaria, Alex[1] *; and Schreiber, Kathleen[2]*
[1] Department of Earth Sciences and [2]Department of Geography, Millersville University, Millersville, PA 17551

We are analyzing observed lightning strike data for southeastern Pennsylvania from 1995 through 2001. The data contains the location, strength, polarity, and date of each strike. Monthly average distributions of number of lightning strikes and percentage of positive lighting strikes (strikes which lower a positive charge to the ground) for 17 counties were created. We've confirmed the results from a study by a prior student (Mike Babij, ESCI) of a slight negative yet statistically significant correlation between elevation and lightning strike density for Southeastern Pennsylvania. We have also tested the monthly lightning strike distributions from the 17 counties for homogeneity, and found that they are not homogenous. Future work will attempt to group the counties having similar monthly distributions with the goal of identifying common geographical factors that may influence the monthly lightning distribution.

16. Linked Environments for Atmospheric Discovery (LEAD)

Meyers, Eric; Vogt, Jen; Sanders, Kyle; Kurdzo, Jim; Kunsman, Hilary; Kelly, Caitlin; Potter, Brittany; Junod, Robert; Banks, Nolan; Plourde, Laura; McKinney, Patrick; Yalda, Sepideh*; and Clark, Richard*
Department of Earth Sciences, Millersville University, Millersville, PA 17551

The project entitled Linked Environments for Atmospheric Discovery (LEAD) is a nine-institution effort funded by the National Science Foundation Information Technology Research Division to improve data access and prediction of mesoscale, high-impact weather. Over the past three years, scientists and engineers have worked together with students and faculty of the Millersville's Meteorology and BSE programs to democratize the implementation of high-resolution modeling and its subsequent visualization for literally anyone who yearns to interactively explore mesoscale phenomena. At the seam between expert scientists/developers and inexperienced end-users are twelve undergraduates at Millersville University (MU) who are currently serving as the core team for testing and providing feedback for numerous tools and Web services that have been developed by the LEAD team, and ensuring that these prototypes (Integrated Test Beds) are congruent with the needs of educators and researchers. In addition, the MU team is leading the development of educational components that incorporate LEAD technology in a Web-based environment that invites guided inquiry.

Key activities described in this poster are: 1) Testing the LEAD portal; 2) Orchestrating the LEAD workflow engine; 3) Steering a high-resolution atmospheric numerical

modeling system (WRF); 4) Visualizing model output using IDV; 5) Developing LEAD-to-Learn educational modules; 6) Building a LEAD ontology vocabulary for use in a data-mining (inquiry/discovery) service. The LEAD effort is poised to revolutionize the way end-users access data and model output, specify (steer) a model domain, assimilate data for model initialization, start a workflow made up of service that run across the TeraGrid, launch a high resolution numerical prediction system, in this case, the Weather Research and Forecasting System (WRF), and visualize the output. The MU team has been submitting jobs via the LEAD portal, testing the complete system, and reporting problems to the developers. The team has also created sophisticated Web-based educational wrappers to guide a user through the process while focusing on the investigation of important meteorological phenomena, such as jet streams, lake effect snowfalls, fronts, land/sea breeze circulations, skew-T log-p diagram, genesis and maintenance of squall lines and associated bow echoes, and the Q-G omega and height tendency equations.

17. Mesoscale and Microscale Marine Meteorological Feature Climatology in the Alaska Region using Synthetic Aperture Radar

Stepp, Matthew D.[1]; Young, George S.[2]; and Sikora, Todd D.[1]*

[1]Department of Earth Sciences, Millersville University, Millersville, PA 17551
[2]Department of Meteorology, Pennsylvania State University, University Park, PA 16802

The Alaska region offers a wide range of marine mesoscale and microscale marine meteorological phenomena. These phenomena include gravity waves, convection, island wakes, convective roll vortices, and gap flows. Each phenomenon requires a distinctly different wind shear and static stability regime. The surface signatures of the above-mentioned phenomena are readily detectable in high-resolution synthetic aperture radar (SAR) imagery of the sea surface. Using an archive of over 30,000 SAR marine images of the Alaska region, we have developed frequency climatology of the above mentioned phenomena. NCEP/ NCAR reanalysis are being employed to provide a corresponding climatology of static stability and wind shear conditions associated with each phenomenon.

18. Present-Day Physical Erosion Rate for Brubaker Run

McKinney, Patrick and Price, Jason R.*
Department of Earth Sciences, Millersville University, Millersville, PA 17551

Using the methods of dilution gauging and sediment separation, we find that Brubaker Run has a considerably lower present-day physical erosion rate than the predicted long-term average. The present-day measured rate is approximately 17,000 g/ha/yr, while the long-term average is approximately 140,000 g/ha/yr. Discharge and erosion rate were found to be inversely proportional. These observations lead us to believe that physical

erosion at Brubaker Run has occurred as infrequent, cataclysmic events. These large-magnitude events likely occurred between approximately 30,000 and 14,000 years ago when the region experienced a cold, stormy, and unstable climate. In addition, when Brubaker Run is compared to other streams within Lancaster County, Pennsylvania, it was determined that streams located in areas of high agricultural activity appear to carry more suspended sediment than those located in areas of low agricultural activity. The Brubaker Run watershed is relatively undisturbed and has a measured physical erosion rate of approximately 4.9 ton/mi^2/yr. In contrast, more agricultural watersheds in Lancaster County have erosion rates ranging from approximately 300-1,000 ton/mi^2/yr. These findings demonstrate the strong influence of land-use on stream suspended sediment loads in agricultural regions.

19. Identifying Anthropogenic Contribution of Potassium in Streams Developed on Carbonate Bedrock

Runkle, Timothy and Price, Jason R.*
Department of Earth Sciences, Millersville University, Millersville, Pa 17551

Samples of stream water were collected in order to assess potassium concentration in the Conestoga and Little Conestoga watersheds. Because these streams flow over carbonate bedrock, any potassium found in the stream water can be attributed to anthropogenic contributions. It was hypothesized that golf courses are a point source of potassium. Potassium levels rise as the streams enter the surrounding area of Lancaster City and generally dissipate as they leave. Point sources of potassium could not be found. It may be hypothesized that the residential use of fertilizer is the non-point source of potassium, however identifying the exact sources and their individual contributions will require further study.

Mathematics - Physics

20. The General Brachistochrone Problem

Gemmer, John (MU 2006); Umble, Ron[1]*, Nolan, Michael [2]*
[1]Department of Physics and [2]Department of Mathematics, Millersville University, Millersville, Pa 17551

Using the calculus of variations and the eikonal equation, we generate solutions to the brachistochrone problem that go well beyond the standard solution on a plane in a constant gravitational field. General solutions on surfaces of rotation in a constant gravitational field are considered. Specific examples of solutions on a cone and hyperboloid are given. Furthermore, families of solutions in an inverse square

gravitational field are generated. These solutions have the interesting property of generating forbidden regions where there appear to be no brachistochrone solution. General theorems about this forbidden region are developed. Finally, we develop solutions that take special relativistic effects into account. These results duplicate the original Newtonian solution as the speed of light becomes arbitrarily large.

Physics

21. Light Pressure on a Diaphragm

Benway, Tanya and Dooley, J.W.*
Department of Physics, Millersville University, Millersville, Pa 17551

A silver plated transparent film is deflected when light from a camera flash lamp strikes it. We have observed the deflection at atmospheric pressure and in a vacuum, finding evidence for both impulsive and thermal components to the deflection. The impulsive response has a rise time less than 50 microseconds, and a time duration of about 5 milliseconds, on the order of the duration of the flash. In vacuum, this is followed by ringing at the natural “drumhead” frequency of the diaphragm for several hundred milliseconds. The presumed thermal response is a relaxation to the original state which takes times on the order of 10 seconds.

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