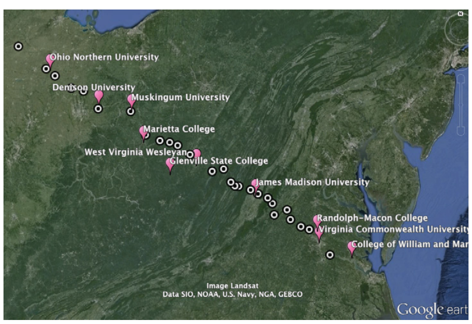
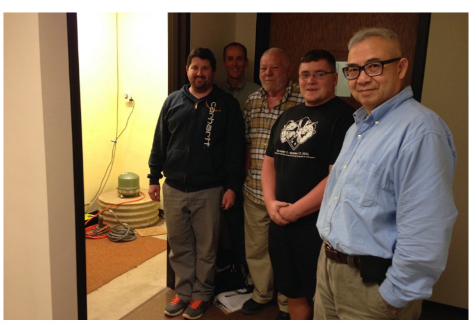
GeoPRISMS and EarthScope education and outreach to predominantly undergraduate institutions in Eastern North America via the MAGIC deployment

Maureen D. Long, Margaret H. Benoit

The Mid-Atlantic Geophysical Integrative Collaboration (MAGIC) experiment involves the deployment of 28 broadband seismometers in a dense linear transect from Charles City, VA to Paulding, OH. Data collection began in Fall 2013 and will continue through Fall 2016. The major E&O component of the MAGIC project involves outreach to faculty and students at primarily undergraduate colleges and universities in our field area, most of which do not otherwise have active ties to the GeoPRISMS and EarthScope initiatives and several of which do not have earth science departments.

Our contacts with faculty at institutions in our field areas typically begin at the siting stage, when we are searching for a suitable location for a seismometer installation in the vicinity of the college. Contacts with faculty, staff, and students at institutions in our field area have proven invaluable to siting the MAGIC experiment. Three institutions are hosting MAGIC stations on their campus (Muskingum U., Denison U., and Virginia Commonwealth U.), while faculty or staff (or their family) at several others are hosting stations on privately owned land. Meetings with faculty and students at our host institutions allow for the MAGIC PIs to learn about the local student body and departments and programs, and allow us to increase awareness of the GeoPRISMS and EarthScope initiatives at local colleges.





Top: Map of MAGIC station locations (white circles) along with institutions that have been involved in the MAGIC and TEENA projects (pink markers). Bottom: photograph of students and faculty from Yale U. and Muskingum U. servicing a MAGIC station (on pier in background) located in the science building on campus, May 2015.

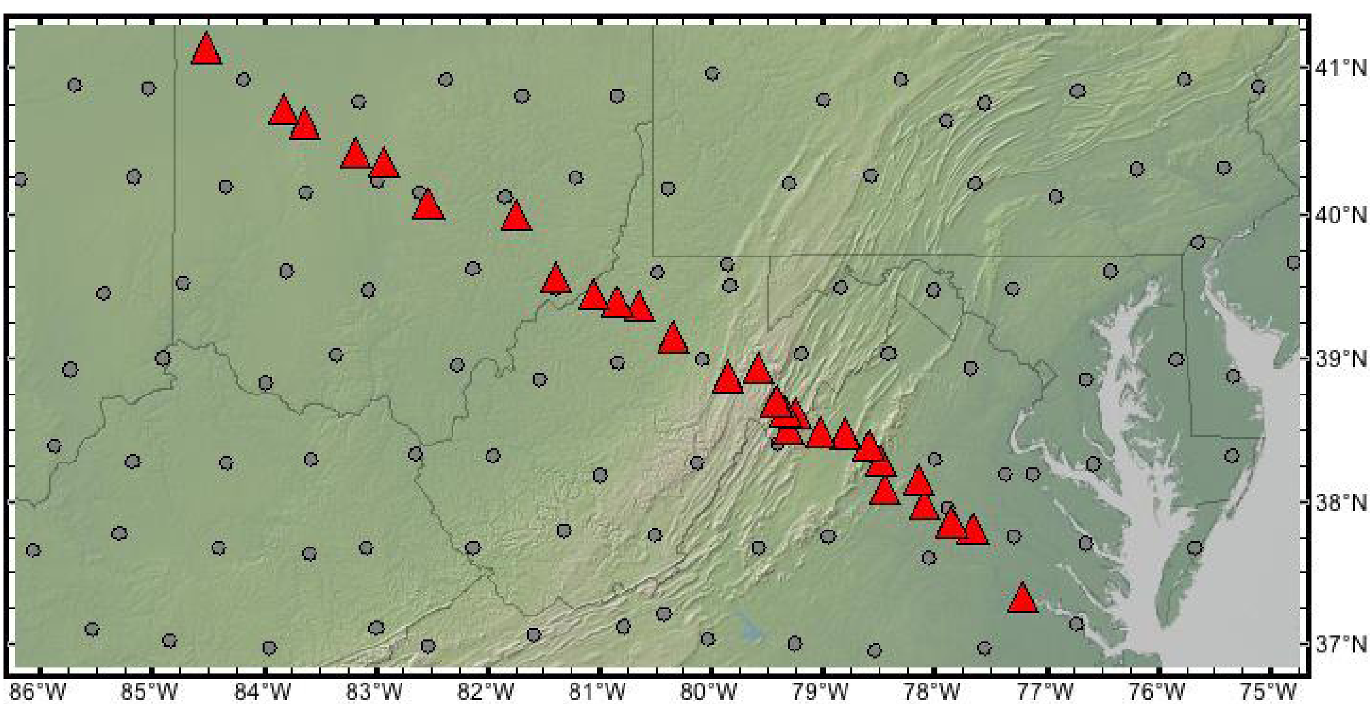
During the course of the field work for MAGIC and its predecessor pilot project (the Test Experiment for Eastern North America, or TEENA), we have worked with faculty, students, or staff from a total of ten institutions: Ohio Northern U. (Ada, OH), Denison U. (Granville, OH), Muskingum U. (New Concord, OH), Glenville State College (Glenville, WV), West Virginia Wesleyan College (Buckhannon, WV), James Madison U. (Harrisonburg, VA), Virginia Commonwealth U. (Richmond, VA), Randolph-Macon College (Ashland, VA), and the College of William and Mary (Williamsburg, VA). At several of our stations, faculty and/or students have joined us for station installation or servicing trips. We are currently planning a MAGIC "lecture tour" to many of these institutions for Spring 2016, during which one of the PIs will visit to deliver a talk aimed at undergraduates on the geologic history of the eastern United States, the science goals of GeoPRISMS and EarthScope, the tools of observational seismology, and the MAGIC experiment. These talks will be tailored to the interests and backgrounds of the students at each institution (in particular, whether the students are physics or geology majors).

Structure and dynamics of the mid-Atlantic Appalachians from seismology, geodynamics, and geomorphology: The MAGIC project

Maureen D. Long, Margaret H. Benoit, Scott D. King, Eric Kirby, Scott R. Miller

The Mid-Atlantic Geophysical Integrative Collaboration (MAGIC) involves a collaborative effort among seismologists, geodynamicists, and geomorphologists to understand the relationships among surface processes, crustal and lithospheric structure, and deep mantle flow beneath eastern North America. The project is funded through the GeoPRISMS, EarthScope, and Geomorphology and Land Use Dynamics programs of NSF, and the science goals of the project are closely linked with those articulated by the GeoPRISMS science and implementation plans for the Eastern Margin of North America (ENAM) focus site of the Rifting Initiation and Evolution (RIE) initative.

ENAM represents a passive continental margin that has been modified by multiple episodes of orogenesis and rifting through two complete cycles of supercontinent assembly and breakup over the past 1.3 billion years of Earth history. It is unclear to what extent deep structures in the crust and mantle lithosphere have persisted over this timeframe, and what controls the pattern of mantle flow beneath the passive continental margin. Furthermore, the persistence of Appalachian topography remains a major outstanding problem in the study of landscape evolution; there is evidence for relatively recent rejuvenation of this topography, which may be



Map of MAGIC station locations (red triangles) along with Transportable Array (TA) station locations (gray circles).

connected to deep mantle flow. Although ENAM has been a passive continental margin for nearly 200 Ma, the eruption of basalts in Virginia and West Virginia during the Eocene (~40 Ma) provides evidence for its relatively recent modification [Mazza et al., 2014]. The two overarching science questions addressed by the MAGIC project are 1) What is the pattern of mantle flow beneath the eastern US continental margin and how has it affected surface topography?, and 2) How does the geological architecture and topography at the surface relate to the deeper structure of the crust and lithosphere?

To address these science questions, we are undertaking a deployment of 28 broadband seismometers as a USArray Flexible Array experiment in a dense linear transect from Charles City, VA to Paulding, OH. The first stations in the array were installed in Fall 2013, with the bulk of the stations installed in Fall 2014. As of June 2015, 27 of the 28 stations are operating, with data collection scheduled to continue through October 2016. The MAGIC data are allowing us to image isotropic and anisotropic crust and mantle structure from the coast to the continental interior, using techniques such as shear wave splitting, receiver function analysis, and tomographic inversions.

The geodynamical modeling effort focuses on quantitatively testing several different hypotheses for the pattern of mantle flow beneath eastern North America by using 3-D, time-dependent, numerical models to make testable predictions about seismic anisotropy in the mantle and (dynamic) topographic change, which will be tested against results from the seismology and geomorphology component of the project. Specific hypotheses to be tested include mantle flow driven by the ancient Farallon slab in the mid-mantle include small-scale convection at the edge of the North American craton. These hypotheses were developed based on preparatory studies of mantle anisotropy beneath ENAM [Long et al., 2010; Wagner et al., 2012] and will be tested against observations made using both the MAGIC stations and stations of the Transportable Array. The geomorphology component of the project uses quantitative stream profile data and cosmogenic isotopes to understand (past and present) erosion rates throughout the central Appalachian region; we hope to identify regional patterns in transient topographic change whose association with crustal and/or mantle features might illuminate the causes of topographic rejuvenation.

References

Long, M. D., Benoit, M. H., Chapman, M. C., and King, S. D., 2010. Upper mantle anisotropy and transition zone thickness beneath southeastern North America and implications for mantle dynamics. Geochem. Geophys. Geosyst. 11, Q10012, doi:10.1029/2010GC003247.

Mazza, S. E., Gazel, E., Johnson, E. A., Kunk, M. J., McAleer, R., Spotila, J. A., Bizimis, M., and Coleman, D. S., 2014. Volcanoes of the passive margin: The youngest magmatic event in eastern North America. Geology, 42, 483-486.

Wagner, L. S., Long, M. D., Johnston, M. D., and Benoit, M. H., 2012. Lithospheric and asthenospheric contributions to shear-wave splitting observations in the southeastern United States. Earth Planet. Sci. Lett., 341-342, 128-138.

Geodynamic Modeling in Support of the MAGIC Project

Scott D. King, Shangxin Liu, Maureen D. Long, Margaret H. Benoit, Eric Kirby, Scott R. Miller

The Mid-Atlantic Geophysical Integrative Collaboration (MAGIC) includes a seismic deployment that extends from the Atlantic coast of Virginia to the western boarder of Ohio as well as using seismic data from the EarthScope Transportable Array (TA) stations and stream profile analyses that provide information about erosion and uplift over the entire eastern third of the US. Prior to the arrival of the TA, analysis of existing broadband seismic stations in the southeastern US detected a distinct pattern of shear-wave splitting: near the coast stations exhibit well-resolved null (no splitting) behavior for SKS phases over a range of back azimuths, consistent with either isotropic upper mantle or with a vertical axis of anisotropic symmetry; farther inland splitting exhibits mainly NE–SW fast directions, consistent with asthenospheric shear due to absolute plate motion (APM), lithospheric anisotropy aligned with Appalachian tectonic structure, or some combination of these (Long et al., 2010). The MAGIC deployment crosses this transition and will help determine crustal thickness and the lithosphere-asthenosphere boundary, in addition to mantle flow direction and transition zone structure.

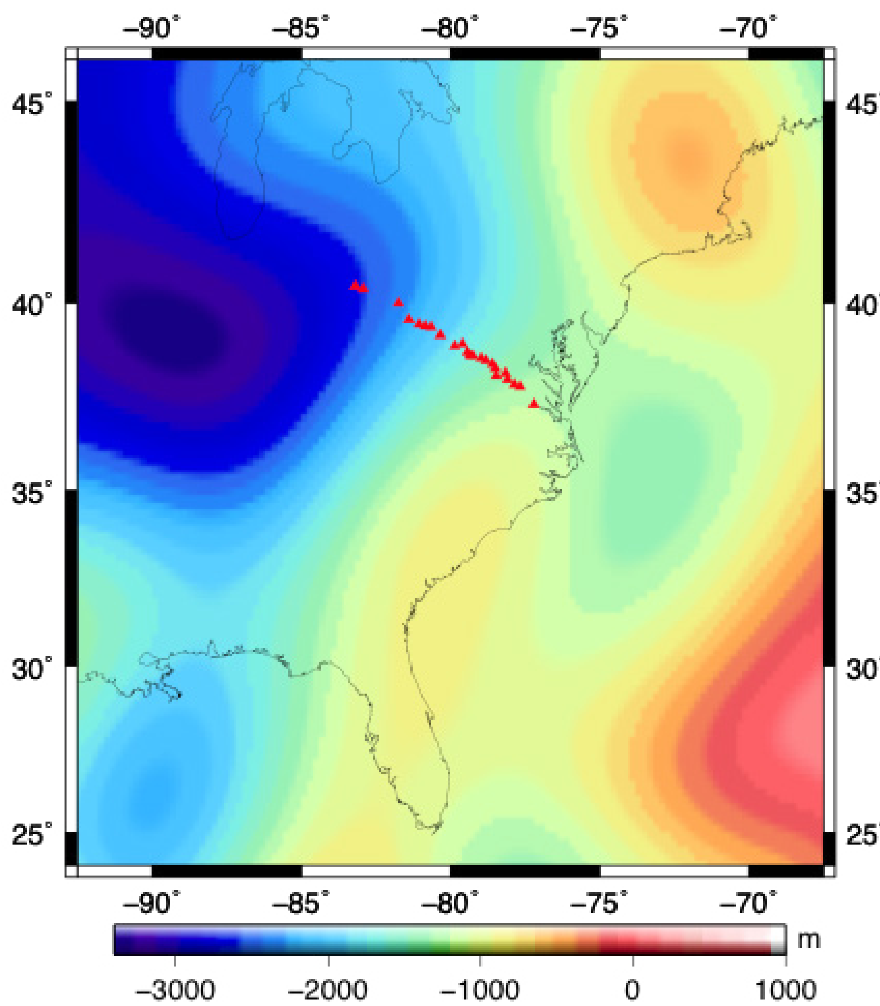


Figure 1. predicted dynamic topography from a geodynamic calculation with uniform mantle viscosity and uniform scaling of seismic velocity to density. The S40RTS seismic model, with a minimum wavelength of 1,000 km is converted to buoyancy to drive mantle flow. The red triangles denote the stations in the MAGIC deployment.

To test hypotheses regarding mantle flow and to aid the interpretation of the observations, we are building a new geodynamic model based on ASPECT (Advanced Solver for Problems in Earth ConvecTion) (Kronbichler et al. 2012) that uses buoyancy derived from seismic tomography along with realistic lithosphere and sub-lithosphere structure. We have tested seismic models S40RTS (Ritsema et al., 2011) and SAVANI (Auer et al., 2014) and we plan to compare these results with newer models, including regional models based on EarthScope data (e.g., Schmandt and Lin, 2014) in an effort to understand the uncertainty in the pattern of seismic velocities. In addition we plan to incorporate crust and lithosphere-asthenosphere boundary models for the eastern US as these become available. In addition to predicting transition zone thickness and patterns of shear-wave splitting, the geodynamic models provide estimates of heat flow, gravitational potential, and dynamic topography. Dynamic topography is the surface deformation induced by viscous stresses resulting from convective flow within the mantle. Dynamic topography varies as mantle flow changes and generally is small in amplitude and long in wavelength. Thus, dynamic topography can be difficult to remove from topographic anomalies resulting from tectonics (Braun, 2010). Most previous estimates of eastern US dynamic topography use long-wavelength seismic models (Spasojevic' et al., 2008).

References

Auer, L., L. Boschi , T. W. Becker, T. Nissen-Meyer, and D. Giardini, 2014. Savani: a variable-resolution whole-mantle model of anisotropic shear-velocity variations based on multiple datasets. J. Geophys. Res., 119, 3006-3034, doi:10.1002/2013JB010773.

Braun, J., 2010. The many surface expressions of mantle dynamics. Nature Geosci. 3,825-3,833.

Kronbichler, M., T. Heister and W. Bangerth, 2012. High accuracy mantle convection simulation through modern numerical methods. Geophys. J. Int. 191(1), 12-29.

Long, M. D., M. H. Benoit, M. C. Chapman, and S. D. King, 2010. Upper mantle anisotropy and transition zone thickness beneath southeastern North America and implications for mantle dynamics, G-cubed., 11, Q10012.

Ritsema, J., A. Deuss, A., H. J. van Heijst, and J. H. Woodhouse, 2011. S40RTS: A degree-40 shear-velocity model for the mantle from new Rayleigh wave dispersion, teleseismic traveltime and normal-mode splitting function measurements. GJI 184 (3), 1223–1236.

Schmandt, B., and F.-C. Lin, 2014. P and S wave tomography of the mantle beneath the United States, Geophys. Res. Lett., 41, doi:10.1002/2014GL061231.

Spasojevic', S., L Liu, M. Gurnis, and R. D. Müller, 2008. The case for dynamic subsidence of the U.S. east coast since the Eocene, Geophys. Res. Lett., 35, L08305, doi:10.1029/2008GL033511.