# Mapping Geomagnetic Field Variations With Unmanned Airborne Vehicles

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Unmanned airborne vehicles (UAVs) are increasingly being used for a variety of commercial and research applications. The small (wingspan ~3 meters), fully autonomous aircraft are well suited for use in remote areas or dangerous settings. UAVs that are launched and recovered on land are being used for atmospheric chemistry and surface imaging studies and for aeromagnetic surveys [*Curry et al*., 2004; *Ramanathan et al*., 2007; *Funaki et al*., 2007]. We report here on the first deployment of UAVs launched from a marine research vessel. The UAVs mapped fluctuations in the magnetic field in a remote area of the southwestern Pacific Ocean.

We collected more than 10,000 kilometers of magnetic anomaly data with the UAV to examine magnetic field fluctuations during the Cretaceous Quiet Zone (KQZ), a 37-million-year interval of uniform polarity that is unique in the geomagnetic record preserved in ocean floor magnetization (see Figure S1, in the electronic supplement to this *Eos* issue (http://www.agu.org/eos_elec)). As new seafloor produced at the ridge crest cools, it captures a record of past geomagnetic field fluctuations dominated by reversals of polarity that generate lineated magnetic anomalies. When calibrated with absolute ages, this pattern of polarity reversals allows the age of the seafloor to be estimated. Magnetic anomaly data have been critical in deciphering the tectonic history of the ocean basins. Such tectonic analysis, however, is not possible for the approximately one quarter of the present seafloor that was generated during the apparently constant normal polarity interval from 121 to 83 million years ago (the Cretaceous Quiet Zone).

Although magnetostratigraphic studies provide strong evidence that the KQZ formed during predominantly normal polarity, there are nonetheless relatively large amplitude variations in many sea surface magnetic anomaly profiles crossing KQZ crust. Detailed studies of comparable short-wavelength anomalies within the Central Anomaly (0–0.78 million years ago), Anomaly 5 (~10–11 million years ago), and elsewhere suggest that the coherent portion of these fluctuations likely reflects geomagnetic intensity variations (or short polarity events in some cases [*Gee and Kent*, 2007]). The amplitude and character of such short-wavelength anomaly variations in the KQZ can potentially provide clues about the origin of the geomagnetic field and, if sufficiently distinctive lineations are present, also provide additional time markers for tectonic studies.

### *UAV Operations*

To evaluate the origin of short-wavelength anomalies within the KQZ, we conducted a survey in the southwestern Pacific Ocean (see Figure S2, in the electronic supplement) on the R/V *Melville* in February–March 2007. The relatively fast spreading (60 kilometers per million-year half rate), minimal sediment cover, and high paleolatitude of formation make this area ideal for evaluating the magnetic anomaly pattern. However, the location is remote and a large number of anomaly profiles are required to demonstrate linearity and to assess the importance of other factors—such as geochemical or thickness variations—that also affect anomaly amplitudes. UAV operations are an ideal complement to this survey, providing substantial (up to fourfold) additional magnetic coverage in areas where bathymetric data and sea surface magnetic data are acquired by the vessel.

We used a GeoRanger UAV (designed by Insitu, Inc., and Fugro Airborne Surveys; Figure 1; http://www.fugroairborne.com) to collect magnetic profiles on preprogrammed tracks (at 200-meter elevation) parallel to


*Fig. 1. GeoRanger unmanned airborne vehicle (a) on catapult in preparation for launch and (b) just after capture. Original color image appears at the back of this volume.*

the ship track. Altitude variation was minimal (~5 meters), and the median horizontal deviation from programmed track points was approximately 12 meters. The prototype UAVs were launched from a pneumatic catapult on the ship's forward 02 deck. Differential GPS navigation allows the UAV to be captured in midair by a wingtip clip that attaches to a rope suspended from a retractable boom on the fantail (see videos at http://magician.ucsd.edu/UAV/). The boom system is extended and rotated perpendicular to the vessel for capture, and then the system is lowered and rotated back to the fantail for recovery of the aircraft. We were able to successfully deploy the UAV in winds of up to 25–30 knots. The nominal endurance of the UAV is 15 hours, which at a cruising speed of approximately 50 knots corresponds to approximately 1350 kilometers. During the nine successful UAV deployments during the cruise, the average flight time was 11.5 hours (maximum 15.5 hours).

The GeoRanger is equipped with a high-resolution (0.001-nanotesla sensitivity) cesium-vapor magnetometer that is sampled at 10 hertz, corresponding to an along-track spatial sampling of approximately 2.5 meters. The signal from the aircraft is small (1–2 nanoteslas), and the UAV magnetic data compare favorably with results from the surface-towed Overhauser magnetometer. Although the UAV is equipped with an Iridium satellite link that provides for operation beyond line of sight, only limited status information is available via the satellite link; and we found that operation of the UAV near the vessel was preferable since the full data stream could be transmitted via a 900-megahertz radio link.

### *Tiny Wiggles in the KQZ*

Results from a portion of the survey (see Figure S3, in the electronic supplement) illustrate how the UAV operations were used to complement the magnetic and bathymetric coverage obtained by the ship. Because the seafloor topography showed evidence of rift propagation as well as the presence of small seamounts, we opted to have essentially complete topographic coverage with the multibeam sonar (swath width ~18 kilometers) and to use the UAV to provide additional coverage where the bathymetry was mapped. With a nominal ship speed of 10 knots, we devised a repeating survey pattern that kept the UAV within line of sight (~40 to 60 kilometers) and provided three additional magnetic lines. The resulting magnetic coverage indicates that as with younger seafloor, quasi-linear short-wavelength anomalies are present within the KQZ. These anomalies can vary on spatial scales smaller than the multibeam swath width, highlighting the utility of obtaining additional coverage with the UAVs.

The results from our survey in the KQZ demonstrate that UAVs can provide a valuable complement to marine magnetic surveys, leveraging ship costs to provide a much higher data coverage. However, as with any new technology, developing a robust system for application in the marine environment is accompanied by some setbacks. Two of the three prototype aircraft were lost during the expedition, though in both cases the likely cause does not appear to be directly related to weather or operation at sea. Because of these problems, the coverage obtained was only a third of that planned. Nonetheless, the 10,000 kilometers of magnetic data from the UAVs exceeded those collected by the surface-towed magnetometer. On the basis of the success of this program, we anticipate that UAVs will play an increasingly important role in a variety of marine research programs.

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# NEWS

## New Legislation Threatens the Teaching of Evolution

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A new twist on an old legislative tactic may help open the door for the discussion of creationism and intelligent design in science classrooms across the United States. While previous attempts have been made to pass legislation regarding the teaching of evolution, new state legislation is being introduced with the purpose of affording "rights" and "protection" to teachers or students "concerning their positions on views regarding biological and chemical evolution," according to the text from several bills. The proposed legislation would lessen the authority of written science curricula and potentially would allow legal protection for teachers or students to discuss nonscientific views of evolution in science classrooms.

Bills that have been introduced in Florida, Louisiana, and Missouri are based on a model bill that the Florida Citizens for Science and others have indicated is connected to the Discovery Institute and its Center for Science and Culture. The center supports research that challenges various aspects of neo-Darwinian theory and that promotes intelligent design.

The legislation has been criticized by the National Center for Science Education (NCSE) and others for assuming false pretenses of allowing academic freedom while actually serving as a vehicle to allow non-scientific discussion in science classrooms; for being a magnet for expensive lawsuits, as has been the case previously with legislation regarding evolution; and for undermining science education.

For more information and to track states where this type of legislation is being introduced, visit the NCSE Web site: http://www.ncseweb.org/. For those who want to write their state legislators to support science education, the National Conference of State Legislatures Web site provides a link with contact information: http://www.ncsl.org/public/leglinks.cfm.

—Elizabeth Landau, AGU Public Affairs Coordinator


*Fig. 1. GeoRanger unmanned airborne vehicle (a) on catapult in preparation for launch and (b) just after capture.*