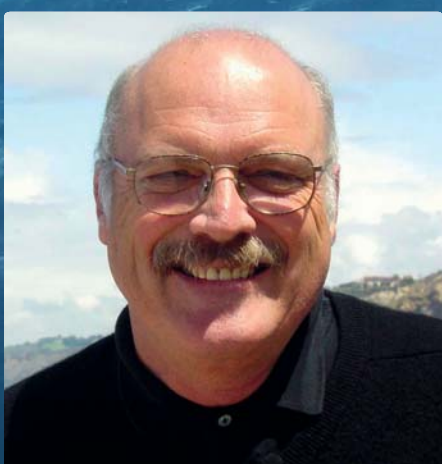
Beyond scanning the **surface**

Efforts to maximise the potential of research instrumentation have led **Professor W Kendall Melville** and his collaborators to develop the Modular Aerial Sensing System, which will significantly augment existing knowledge and benefit researchers in the Earth, ocean and engineering sciences



First, could you explain the NSF's Major Research Instrumentation Program – Recovery and Reinvestment (MRI-R^2) opportunity, from which the Modular Aerial Sensing System (MASS) project emerged?

The Major Research Instrumentation (MRI) Program – Recovery and Reinvestment (MRI-R^2) was separate from the standard annual MRI Program. It provided one-time funding under the American Recovery and Reinvestment Act of 2009 (ARRA), and had special award conditions consistent with ARRA. The Program was generated to ensure that some of the financial stimulus of the U.S. economy by the Federal Government following the global financial crisis of 2008 went into instrumentation in support of science and engineering research with grants ranging from US $100,000 to $6 million, for a total Program budget of $200 million.

This was an excellent use of the stimulus since it provided a funding source for expensive research equipment that has the potential to significantly increase U.S. research capabilities.

The MASS instrumentation must be 'shared use' and not utilised by just one research group. In both preparing the proposal and executing the Program the benefits of exploring broad-based application of the instrumentation has been beneficial. It forced us to consider new applications for the instruments – both separately and as a system.

Your working group has used MASS to improve data on ocean processes and air-sea-land interaction. Could you outline these efforts?

Our initial foray into airborne oceanographic research used visible imagery to measure the kinematics and statistics of surface-wave breaking in deep water. Most of the momentum flux from the atmosphere to the ocean (ie. from the wind to ocean currents) passes through the surface wave field before being transferred to surface currents by breaking. Similarly with the energy flux – some ends up in the kinetic energy of currents while the remainder leads to turbulent mixing of the upper ocean before being dissipated by viscosity.

This led to the need to incorporate wave breaking processes into improved models and predictions of surface waves and currents and therefore a need to simultaneously measure breaking using imagery, and the surface waves using lidar. The surface currents can be measured using ocean surface temperature (through infrared imagery) and other constituents (eg. chlorophyll, through hyperspectral imagery) as passive tracers that can be tracked over short time frames to measure the velocity. To make all of these airborne measurements it is necessary to know where the instruments are in 3D space and time, and where they are pointing. This is achieved using a very accurate GPS and inertial motion unit (GPS/IMU).

The same instrument package can be used to measure a wide range of air-sea-land processes, including beach and cliff erosion due to winter storms, and coastal land subsidence due to torrential rains and runoff.

At what stage are your research activities? What have been the greatest achievements to date?

Our initial work on wave breaking statistics and lidar wave measurements produced a cover article in *Nature* in 2002. Since that

time, we have conducted an extensive airborne experiment in the Gulf of Tehuantepec in 2004, measuring the atmospheric boundary layer, the surface waves and wave breaking as the Tehuanos winds blew out from the coast of Mexico over the Pacific. These datasets from the field have led to an improved wave prediction model that incorporates our better understanding of wave dissipation due to breaking. The datasets have also been used along with laboratory data on wave breaking to infer the strength of breaking across the wave spectrum. The spatial measurements of the wave field have permitted us to measure the spatial statistics of surface waves at a resolution never achieved before; statistics that are important for risk analysis of offshore structures and vessels.

How has your collaboration with the NSF-funded Center for Ocean Science Education Excellence, California (COSEE-CA) emerged?

COSEE-CA specialises in creating partnerships between members of the research and education communities so that researchers can make effective contributions to established programmes in science education and outreach. Now successful integration of the MASS system is complete, we are planning collaboration with COSEE CA (www.coseeca.net) to extend the impact of our research, in air-sea interaction and climate, beyond the bounds of academia.

Airborne observation options

Earth Observation efforts could be dramatically improved with the development of smaller, lighter and cheaper lidar scanners. The **Modular Aerial Sensing System** is leading the way in demonstrating the success that can emerge from a collaborative approach to developing joint-use technologies

SATELLITE REMOTE SENSING has enabled remarkable progress in the ocean, Earth, atmospheric and environmental sciences through its ability to provide global coverage with ever-increasing spatial resolution. However, whilst the temporal coverage of low Earth orbiting satellites may be sufficient for mesoscale ocean processes with time scales of a month, it is not sufficient for processes such as ocean-atmosphere interactions that respond to atmospheric forcing with time scales of hours or days.

Airborne scanning Light Detection and Ranging (lidar) addresses some of this shortfall and is widely used as a mapping tool for a variety of applications in geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing and atmospheric physics, along with laser altimetry and lidar contour mapping. Coastal and near-shore ocean surveys in particular do not require the range or capability of larger aircraft, so there is an incentive to develop smaller, lighter, and cheaper lidar-based systems that can be used in small single- or twin-engine aircraft.

TACKLING THE TASK

Addressing this need for improved lidar-based systems is a collective of research groups based at the Scripps Institution of Oceanography and the Mechanical and Aerospace Engineering Department at the University of California, San Diego (UCSD). Under the National Science Foundation's Major Research Instrumentation Program – Recovery and Reinvestment (MRI-R^2), the team has developed a Modular Aerial Sensing System (MASS). The project – led by Professor Ken Melville from the Marine Physical Laboratory and the Physical Oceanography Research Division of Scripps Institution of Oceanography (SIO) – involves the acquisition, integration and testing of an airborne remote sensing system comprised of a waveform scanning airborne lidar, a hyperspectral camera, a high-resolution video camera, an infrared camera, a GPS/inertial motion unit, data acquisition and post-processing hardware and software. The system has been tested and developed to address a range of significant Earth Observation challenges as well as considering the use other groups could make of such equipment.

WATER SUPPLY

The water supply in many regions of the globe and in particular over much of the western U.S. – including the Sierra Nevada and the Rocky Mountains – is dependent upon spring and summer runoff derived from snow-fed mountainous watersheds. Managing this resource is challenged by changes in the amount of snowpack and the timing and magnitude of snowmelt runoff, which have already been detected. The current system for measuring snowpack is based on a sparse network of manual surveys and in situ sensors scattered across the mountain ranges; but the system is spatially under-sampled.

As part of the NSF MRI project, Melville's group worked with Dr Dan Cayan at SIO to deploy a ground-based scanning lidar. The instrument operated for 4 months to measure the snowpack and flights were conducted with the airborne lidar over the site to compare the two sets of measurements: "We found excellent agreement with the airborne and ground-truth data confirming the usefulness of airborne waveform lidar to measure snow cover both above and below the tree-line," Melville highlights. When coupled with regional climate forecasts, these datasets will provide greatly improved predictions of water resources and data for improved water management.

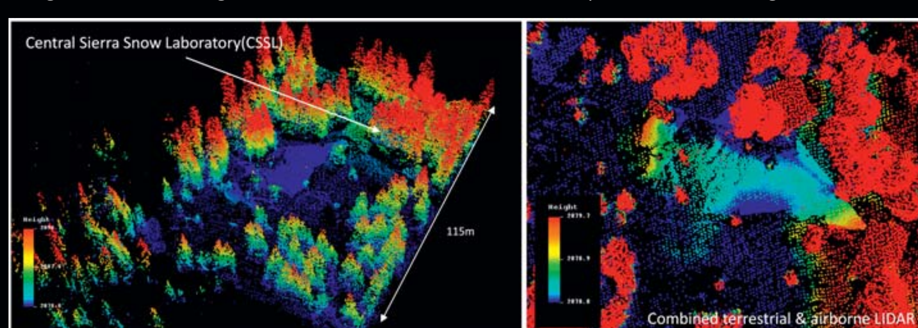


FIGURE 1. Snow elevation measurements at the Central Sierra Snow Laboratory (CSSL) during winter 2010/2011 using terrestrial and airborne lidar (Riegl Q240i and Q680i respectively).

INTELLIGENCE

ACQUISITION OF AIRBORNE REMOTE SENSING SYSTEM FOR OCEANOGRAPHIC, TERRESTRIAL, AND ENVIRONMENTAL RESEARCH

OBJECTIVES

The acquisition, integration and testing of the components of an airborne remote sensing system comprised of a waveform airborne lidar, a hyperspectral camera, a high-resolution video camera, an infrared camera, a GPS/inertial motion unit, data acquisition and post-processing hardware and software, and the labour and supplies to integrate and test the system over two years.

KEY COLLABORATORS

Dr Daniel Cayan, SIO • **Professor Robert Guza**, SIO • **Dr Mati Kahru**, SIO • **Professor Jan Kleissl**, UCSD • **Dr Cheryl Peach**, SIO/COSEE CA • **Mr Luc Lenain**, SIO

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W KENDALL MELVILLE, a native of Australia, has spent most of his professional career at Massachusetts Institute of Technology (MIT) and Scripps Institution of Oceanography, UC San Diego, where he is a Distinguished Professor. His research interests include the application of fluid mechanics in oceanography, especially in air-sea interaction, ocean waves and remote sensing.

COASTAL DATA

Over the last 37 years, SIO has developed the Coastal Data Information Program (CDIP) wave observation and modelling network (http://cdip.ucsd.edu/themes/cdip/about) which reports and archives the predicted wave characteristics at the 10 m contour, updated hourly, for every 100 m interval along the coast of southern California.

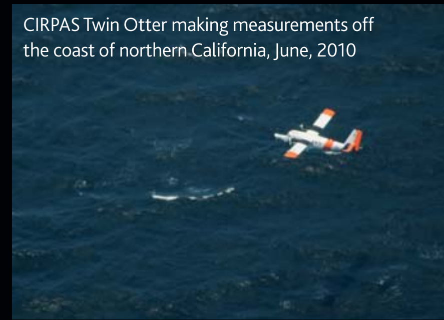
The contrast between the availability of wave data on this coast and the dearth of beach response data could hardly be greater. Lidar provides the means for making accurate surveys of a wide variety of beach types before and after major storms. The availability of precisely matched photography enhances the value of the lidar contour mapping by allowing for identification of cobbles and rock outcrops that influence beach response.

Moreover, precise elevation and photographic mapping of the backshore area in southern California will provide valuable data for predicting inundation zones and structures at risk as a result of sea level increase resulting from El Niño or as a result of sea level rise from climate change. The geology of the southern California coastal region varies significantly over small distances. Precise lidar and photographic surveys, taken before and after major erosion events, will provide data on these episodic beach volume changes. This information will also facilitate the development of much-needed probabilistic models for cliff failures based upon an understanding of the local geology.

CORAL REEF RESEARCH

It is well known by now that coral reef systems are subject to a number of environmental threats due to both climate variability and more explicit anthropogenic sources of pollution. The detailed monitoring of large reef systems, like the Great Barrier Reef (GBR) by in situ techniques, is prohibitively expensive and satellite-based monitoring does not yet have the resolution to monitor the many smaller reef-lagoon systems.

Under the direction of Professor Jason Middleton at the University of New South Wales, Australia, reef research and oceanography classes have been conducted at Lady Elliot Island for many years. Working with Middleton, the MASS team was funded by the Australian Research Council and internal SIO funding to measure the relationship between the dissipation of the surface wave field and the turbulence and mixing in the LEI reef-lagoon system: "By showing that there is a strong correlation between the wave dissipation and turbulent mixing and dissipation in the lagoon, and that the wave dissipation can be measured with airborne lidar, we demonstrated that



CIRPAS Twin Otter making measurements off the coast of northern California, June, 2010

one important component of nutrient uptake related to turbulent mixing can be measured from the air," Melville elucidates.

URBAN ENVIRONMENTS

MASS also incorporates the built environment. High surface and air temperatures in urban environments are caused by the Urban Heat Island (UHI) that results from small sky view factors, anthropogenic heating, and the replacement of natural landscapes with impervious dark surfaces.

In general, the urban surface is a highly complex, human-natural coupled system that has only begun to be studied in an integrated fashion. The surface 'skin' temperature is critical to the UHI effect and building heat transfer processes. Internal building and outdoor temperatures and heat fluxes are coupled by the surface skin temperature, which can be remotely sensed from the MASS system.

ASSESSMENT

The applications of MASS are clearly broad-ranging and of practical use to a large number of environmental researchers. The principal objectives of the MRI-R² funded work were to test and integrate the components of the MASS system during the funding period, and, during that time, demonstrate some of the capabilities of the system to encourage its use, not only by the co-PIs of the grant at UCSD/SIO, but also other colleagues at UCSD/SIO and other institutions. Melville is clearly proud of the achievements of everyone working on the MASS development project and is unequivocal in his assessment of their success: "We believe that we have succeeded by demonstrating its capabilities in measuring ocean waves, beach and backshore processes, red tides off SIO using hyperspectral imagery, ocean surface temperature and surface turbulence, ocean fronts, the Sierra snowpack, and finally, the built environment". The work clearly demonstrates the exceptional achievements that can be made on multiple fronts when a multidisciplinary team successfully addresses the need for value in technology development.