Project Details

Name of project: "**Deep optical wave gauging.**" Real-time gauging of ocean wave height, period and direction from imagery of the surf zone using deep convolutional neural networks.

Project lead and contact details: Dr. Daniel Buscombe, School of Earth and Sustainability, Northern Arizona University, Flagstaff, AZ 86011, daniel.buscombe@nau.edu, 928-890-8504.

Project partners and contact details: Dr. Jonathan Warrick, and Dr. Shawn Harrison, Pacific Coastal and Marine Science Center, U.S. Geological Survey, Santa Cruz, CA, jwarrick@usgs.gov; srharrison@usgs.gov. Dr. Margaret Palmsten, Naval Research Laboratory, John C. Stennis Space Center, MS, meg.palmsten@nrlssc.navy.mil. Dr. Katherine Brodie, U.S. Army Corps of Engineers, Coastal Hydraulics Lab, Field Research Facility, Duck, NC, Katherine.L.Brodie@erdc.dren.mil.

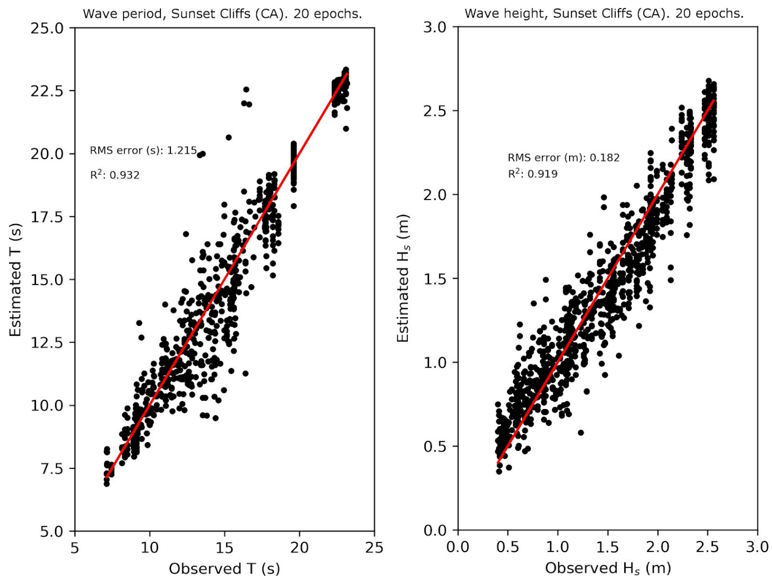
Proposed start and end date: 1/1/19 - 8/1/19 (or ongoing, depending on funding)

Budget Requested: $8,087

Budget Summary: Funds are requested to purchase two custom-built computers: 1) an open-hardware server optimized for and dedicated to building/training deep learning models on large input data sets to predict wave parameters from imagery; 2) a fanless industrial PC that will be used for real-time processing of wave imagery at a pilot field system (the rest of which is funded in-kind by the U.S.G.S.). 1) $6595: "Thelio Massive" custom-build computer by System 76 (Colorado, USA). Features include: easily expandable in future with additional GPU, CPU, and RAM slots; 3 year labor and parts warranty. Customized upgrades: Intel Xeon 10 core Silver 4114 (2.2 – 3 Ghz – 20 threads – 2400 Mhz); 64 GB CPU-RAM (4 x 16 GB quad channel at 2666 Mhz); 500 GB NVMe M2 high speed SSD (read: 3.4 GB/s, write: 2.3 GB/s) for active storage; 2 TB SSD (read: 0.55 GB/s, write: 0.52 GB/s) for storage; 11 GB GeForce RTX 2080Ti (4352 CUDA cores). 2) $1492: Industrial Intel Skylake Mini-ITX custom-built field computer made by Logic Supply (Vermont, USA) with 2 Year Standard Warranty, and the following customized hardware upgrades: Intel Core i3 3.3 GHz CPU; 16 GB CPU-RAM; 1 TB 2.5" SSD; dual-band high-speed Wi-Fi. PI Buscombe is a research professor, 100% supported by external grants.

Project Outline

Project description: "**Deep optical wave gauging**" is a technique currently being developed by Daniel Buscombe that predicts ocean breaking wave height, period (time between wave crests), and direction from photographic images of the surf zone collected using fixed camera installations. The technique utilizes deep convolutional neural networks (DCNNs) to automatically extract features from imagery and predict wave statistics directly. Initial results (Buscombe et al., *in prep*) using a dataset consisting of



paired imagery and an ADCP deployment for measured wave parameters at one site, included RMS errors of just 18 cm for wave height, and 1.2 s for wave period (see figure), using numerous modified architectures, and the models will improve when trained for longer. There are several indications that the technique will transfer well to new sites, which we hope to demonstrate in this incubator project. If so, the technology has enormous potential for remote coastal wave monitoring at large scales without costly installation and retrieval of buoys and inshore instrumentation by boat. ***We request funds to help move the system towards an operational phase***. This will require two concurrent initiatives that will serve to pilot the technique at the field scale, and carry out the research and development required to generalize the model and demonstrate its potential for real-time wave gauging at multiple sites. 1) ***Real- time wave monitoring at a pilot location***. We propose to install a pilot coastal monitoring camera system (https://on.doi.gov/2PIBMbp) at a location (to be decided), in order to analyze imagery in real-time and push estimated wave statistics to an online data server. To do this, we request $1492 to purchase a small industrial PC that will carry out image processing in the field. The rest of the internet-connected system will be provided and maintained by the USGS partners. Every 10 minutes, a snapshot will be taken and instantaneously analyzed for wave parameters, which will then be relayed to an online database. 2) ***Neural network optimization/generalization to new sites***. There is real potential to develop generalized models for similar sites, such that wave statistics may be estimated from imagery at an arbitrary site given appropriate choice of available 'off-the-shelf' models. Right now, separate models exist at one site for wave height, period, and direction. We aim to modify the DCNN architecture so it estimates all three quantities simultaneously, as well as pool training data from several sites in order to develop a more universally applicable model. We will therefore continue to research optimal network architectures and hyperparameters, by training models on large archived image data from multiple sites provided by project partners at the USGS, Naval Research Laboratory (NRL) and the US Army Corps of Engineers (USACE). Exploring, optimizing and training these DCNNs requires long training times and large computational power, including GPUs with 10+ GB of onboard memory. We request $6595 to build a server dedicated to training from massive image archives. We researched cloud computing options, finding that the purchase of this hardware was by far the cheaper option considering the number of large-GPU-instance hours required. With the new server, we will be able to use paired archived image sets and inshore wave measurements to optimize the technique for a number of sites, including Santa Cruz (CA), Molokai (HI), and Duck (NC). Once operational, periodically we would update it with new imagery.

Project objectives, significance and impact. There are two major objectives: 1) Build a web-enabled camera system to estimate wave height, period and direction from a single snapshot and, in real-time, upload that data to a web server. Collect at least 1 year of imagery, to maximize the range of captured conditions. The system will pilot the technique applied to a field setting, demonstrating its utility as a remote wave gauge. 2) Develop a neural network classifier to predict wave height, period and direction, individually for each site (the pilot field site, as well as archived imagery from other coastal existing systems), and a more universally applicable model optimized for generic wave prediction from imagery.

Description of key project steps and timeline. Winter 2019: purchase computing equipment; build server and field systems; field site selection. Spring 2019: deployment of field camera system at pilot site; start training/optimization of deep convnets on data from Santa Cruz and Molokai sites. Summer 2019; finish initial Santa Cruz and Molokai site models, start training on data from Duck and pilot site; present initial results at ESIP summer meeting. Fall 2019; finish initial training on data from Duck and pilot site. Update Santa Cruz and Molokai site models with new imagery; update Duck, pilot site, and Sunset, Molokai models. Create a generalized model for all sites. All project partners will collaborate on writing a journal article exemplifying the system.

Outreach

What groups/audiences will be engaged in the project? "Deep optical wave gauging" has enormous potential for remote coastal wave monitoring at large scales without costly installation and retrieval of buoys and inshore instrumentation by boat. A full web-enabled camera monitoring system with real-time telemetered imagery can be built for $4000 or less, so this might be an especially cost-effective means with which to monitor coastal waves, especially in developing countries and/or remote locations. We plan to open-source both the camera system hardware and the software that carries out the model training and predictions. Therefore, other researchers and agencies with coastal wave gauging needs will benefit immediately. For example, USACE has already installed continuous video monitoring stations at 4 of their coastal project sites nationwide, with plans for significantly more installations over the coming three years to improve management of federal beach projects. "Deep optical wave gauging" would transform the ability of these stations to better predict beach evolution and coastal structure impacts. The project will also serve as a practical case study on the quantitative monitoring of societally important physical phenomena using consumable hardware and data-driven models.

How will you judge that project has had impact? We anticipate there to be considerable interest in successfully demonstration of the technique from the academic community as well as regulatory agencies, consultancies and other parties/agencies that measure waves. We will measure impact through interactions with colleagues at specialized meetings such as the Coastal Imaging Research Network (CIRN) annual meeting, as well as tracking citations to published articles, and tracking downloads/issues/pull requests in the project's github repository. Upon successful completion of this pilot, we hope to apply for funds to support a potential broader goal of wave gauging in remote environments or using satellite imagery.

How will you share the knowledge generated by the project? We aim to give presentations at ESIP summer meeting, the AGU Fall Meeting, and the CIRN annual meeting, and anticipate publishing an article demonstrating the technique in a suitable academic journal. We would hope to advertise the project through ESIP and partner social media channels. Further to academic avenues, we will also reach out to recreational groups such as Surfline, CoastalWatch, or MagicSeaWeed. For example Surfline.com broadcasts live imagery from over 360 "surfcams" worldwide (including 221 in the US). We could potential apply optical wave gauging to their video streams to estimate wave statistics at each location, which would provide better localized wave conditions than wave model (e.g. LOLA) forecast values, impacting potentially millions of people looking for better situational awareness of the coastal zone.

Project Partners

Description of project partners (individuals and/or organizations) and their involvement: PI Buscombe is engaged in various applications of machine learning in geomorphology, sediment transport, and biophysical acoustics. All project partners work on coastal imaging for federal agencies, providing basic information on coastal waves and morphology for the Nation. Partners Palmsten, Brodie, Harrison and Warrick research various aspects of remote sensing, coastal hydrodynamics, sediment transport, coastal morphology and hazards at, respectively, the NRL, the USACE Field Research Facility in Duck, NC, and at the USGS in Santa Cruz, CA. All partners will provide archived image and wave data, help implement the pilot field system, and contribute ideas toward model development during conference calls.

How will this project engage members of the ESIP community: Many ESIP members also work for the institutions represented by the project partners. Through attendance of ESIP meetings and project reporting, we hope to inspire ESIP members to carry out low-cost environmental monitoring, harnessing relatively cheap hardware and the power of deep learning.