Remote Sensing of Shallow Water Bathymetry for Integration with Multibeam SONAR Data

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Impetus

In the past five years, over 60,000 km^2 of high-resolution multibeam bathymetric data have been collected around the U.S. Pacific Islands, but there are substantial gaps in coverage over the 0–20 m depth range. Derived bathymetry from satellite imagery is currently the only product capable of filling the gaps quickly and relatively cheaply, as there already exist archives containing usable images from various sources (Landsat, IKONOS, Quickbird). However, it remains uncertain whether satellite-derived data are accurate enough to help fulfill management requirements for continuous bathymetric maps across the entire 0–300 m depth range. In the absence of satellite-derived bathymetry products, it would become necessary to obtain the data from alternate—and more costly—sources (i.e., SONAR, airborne LIDAR).

Objectives

The goals of this project are to better define the process and feasibility of deriving bathymetry and to determine whether resulting products are potentially useful for resource management needs. There were five primary objectives for Year 1:

- Derive shallow water bathymetry from satellite imagery for select sites in the Pacific, using existing bathymetric data (SONAR, LIDAR) to constrain and evaluate the depth estimates.
- Compare different methods for deriving bathymetry from satellite imagery, both in terms of ease of application and in terms of product quality.
- Generate seamless bathymetry products, combining SONAR/LIDAR with satellite results.
- Standardize techniques for deriving bathymetry from satellite imagery.
- Train additional personnel in use of these techniques.

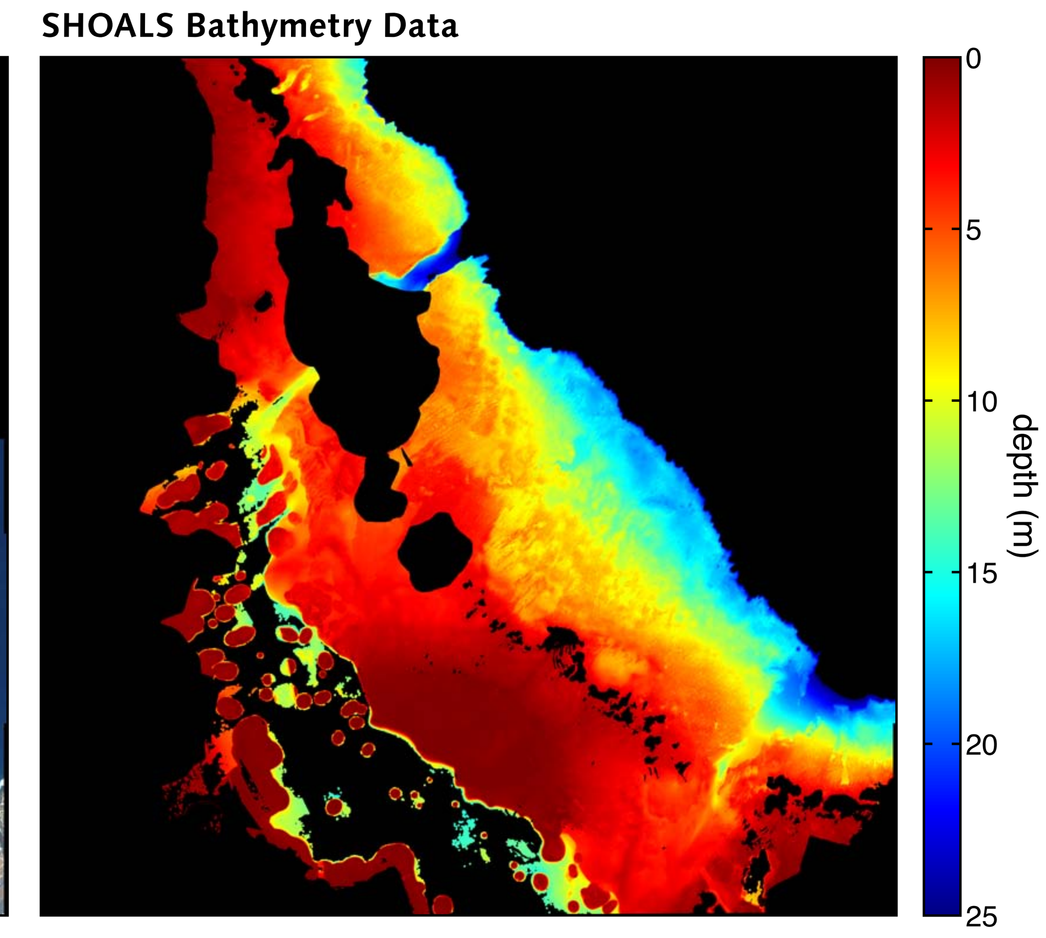
Evaluating Bathymetry Derivation Methods

We tested seven published bathymetry derivation approaches on several different image data sets across the Pacific. For brevity, we report here only selected results for a single image from Kaneohe Bay, Oahu, Hawaii.

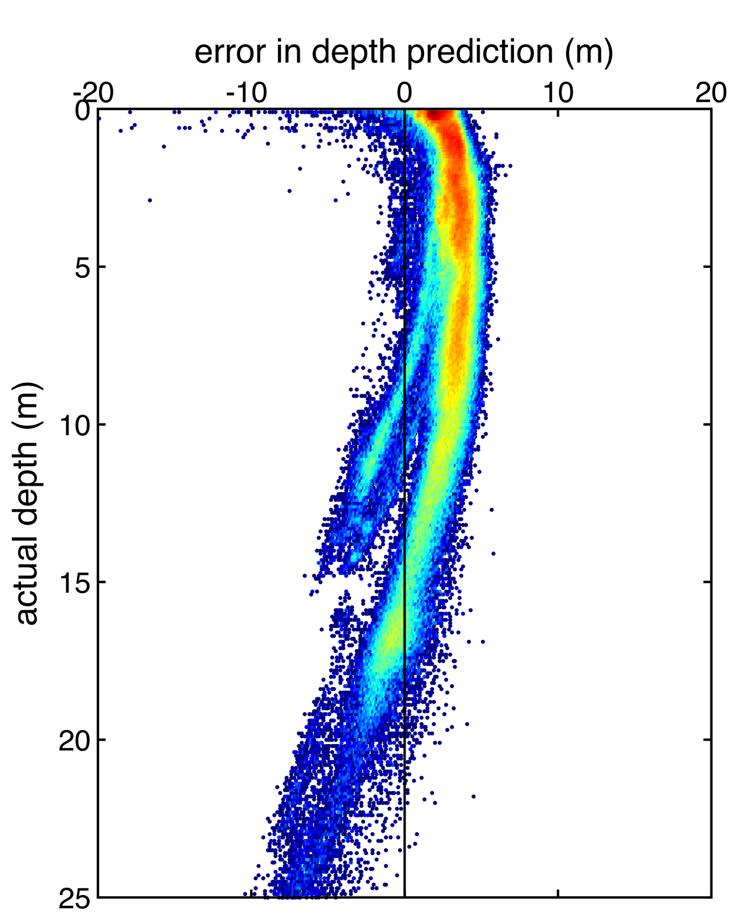
- The image data were acquired by IKONOS on 21 March 2001 (source image ID 2001032121045380000011601918). Data were calibrated to at-sensor radiance.
- Independent bathymetry values were obtained from SHOALS LIDAR data acquired in 1999-2000 (shoals.sam.usace.army.mil).
- SHOALS data were rasterized (Generic Mapping Tools' surface function) to create a bathymetric surface at the same 4-m pixel resolution as, and coregistered with, IKONOS data.
- Prior to analysis, IKONOS imagery was deglinted and binned (3x3 pixels) to improve signal-to-noise.
- Analysis was only performed on valid submarine pixels (no land, breaking waves, clouds, cloud shadows, etc.) in the depth range 0–25 m.
- For methods that required calibration with existing depth data, only values >10 m were used. Thus, predictions for pixels at depths ≤10 m are unbiased.
- Two methods (Bierwirth et al. 1993, Isoun et al. 2003) required water column attenuation as input; average Kaneohe Bay values were used.
- One method (Stumpf et al. 2003) required solar irradiance as input; we used modeled values.

IKONOS Image Data

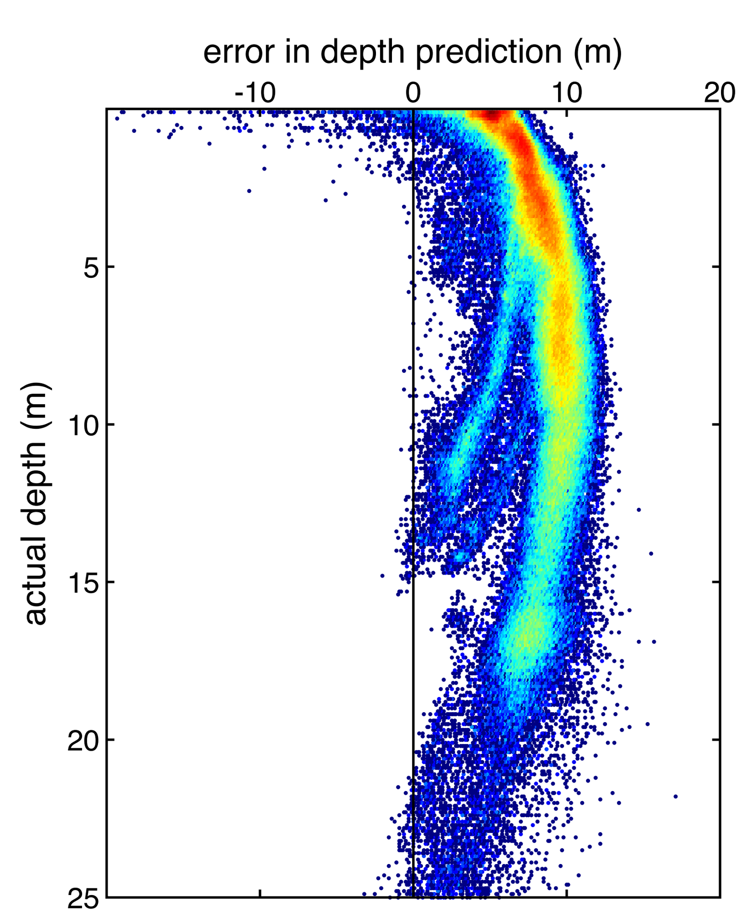
SHOALS Bathymetry Data



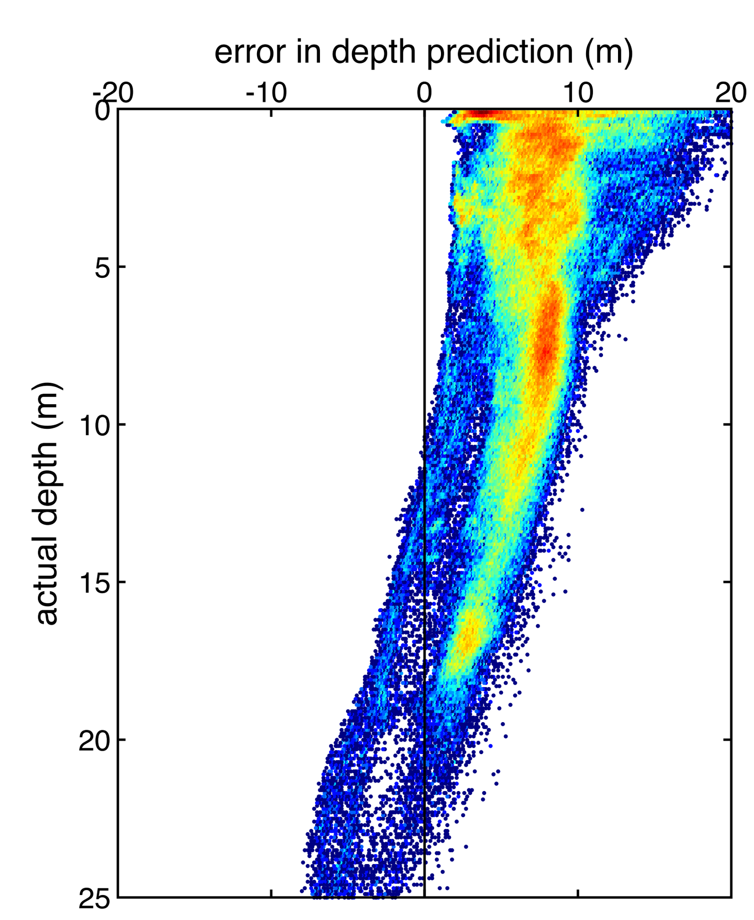
Lyzenga (1985)
- Linearize wavebands
- Multiple linear regression against known depths



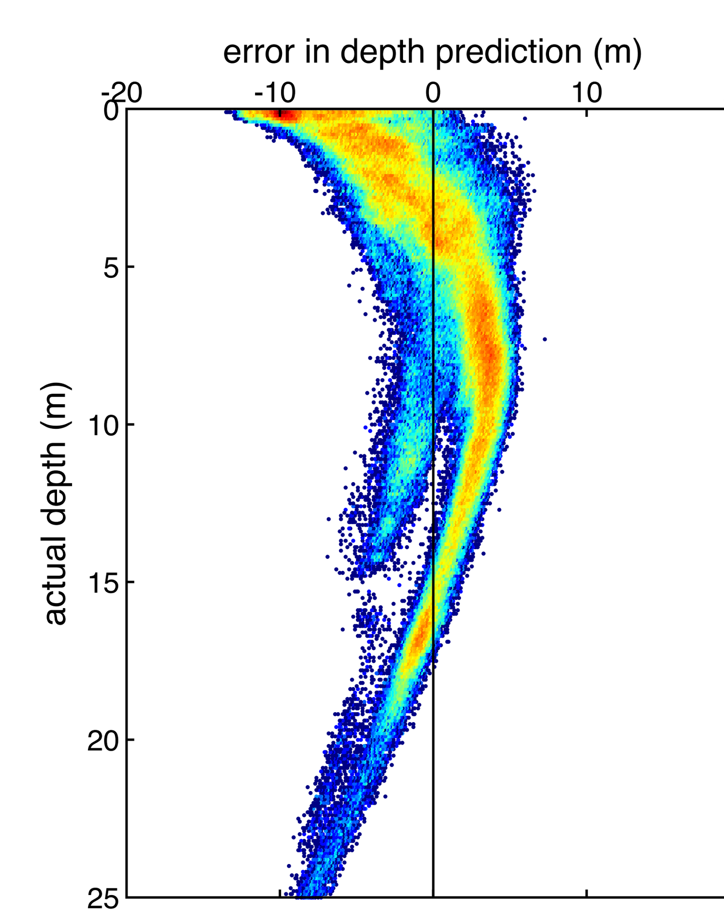
Lyzenga et al. (2006)
- Linearize wavebands
- Multiple linear regression coefficients provided in reference



Bierwirth et al. (1993)
- Linearize wavebands
- Band ratio
- Requires values for water column attenuation



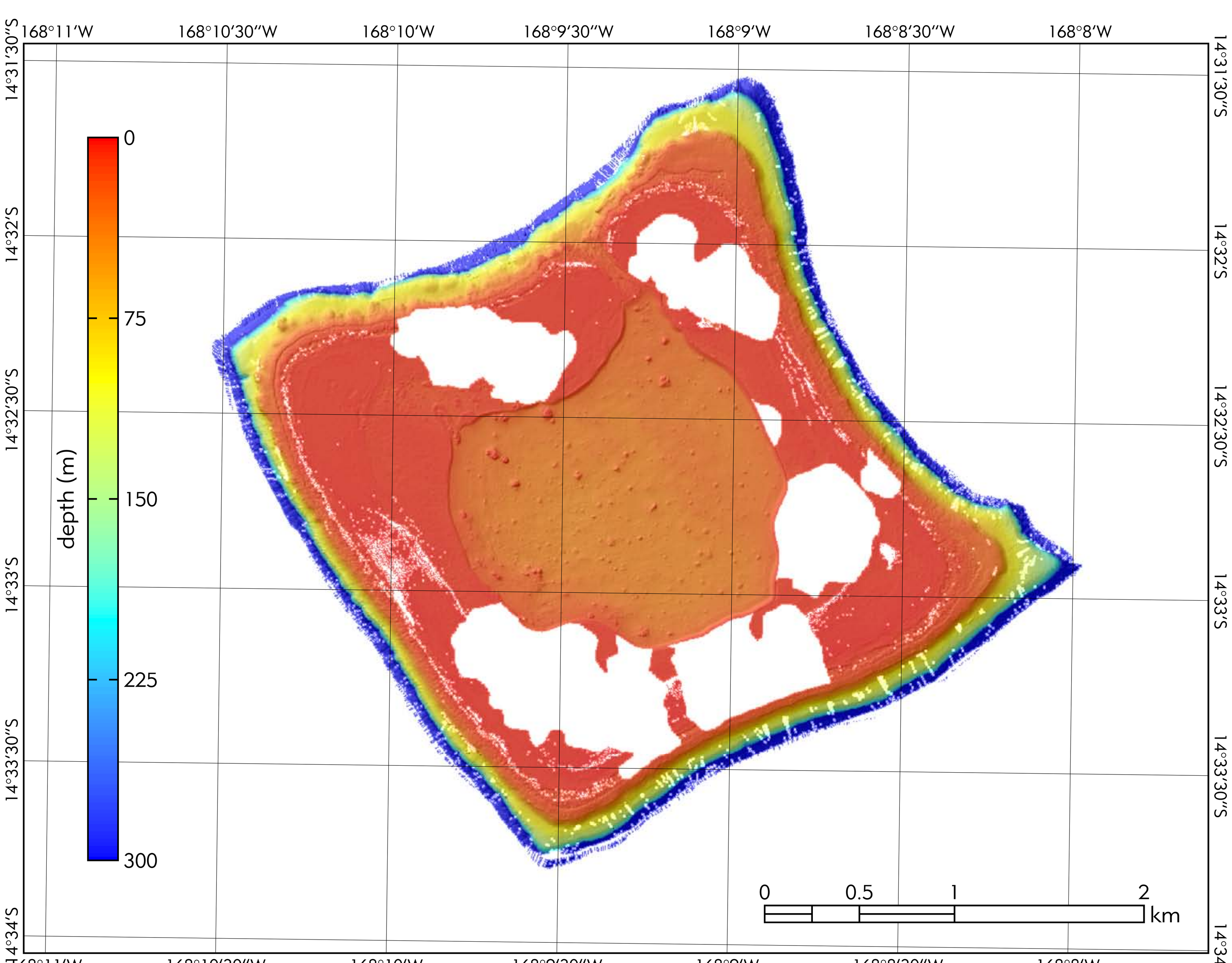
Stumpf et al. (2003)
- Linearize wavebands
- Band ratio
- Calibrate against known values to obtain absolute depth
- Requires values for solar irradiance



These figures show errors in depth predictions (predicted depth - actual depth) for four of the methods tested in this project.

- The most accurate method was simple, empirical multiple linear regression against known depths (Lyzenga 1985).
- These results are representative of all image sources and sites investigated thus far.
- All methods appear sensitive to variations in water and seafloor optical properties.
- Environmental conditions (clouds, sea state, turbidity) appear to be most significant factors influencing quality of results (not shown).
- It is problematic to obtain appropriate ancillary optical data (water optical properties, incident irradiance) for those methods requiring such inputs.
- These initial depth derivations require further "expert" processing to generate more accurate and useful products.

Integrating Satellite-Derived and Multibeam SONAR Bathymetry



This figure shows an integrated bathymetry product for Rose Atoll, American Samoa.

- Water depths >20 m were obtained using multibeam SONAR.
- Water depths <20 m were derived from an IKONOS image following the method of Lyzenga (1985).
- Significant expert manipulation (trained graduate student level) was performed to generate shallow water bathymetry product suitable for integration with multibeam data.
- Result is continuous bathymetric surface across 0–300 m depth range (gaps in data are clouds, cloud shadows, breaking waves).
- The two data sets align well, but there is a visible seam along the northwest and southeast faces of the atoll.

Considerations

- Deriving shallow water bathymetry from satellite image data is feasible.
- Suitable image data exist for most sites in the U.S. Pacific Islands.
- Generating a bathymetry product suitable for integration with multibeam SONAR data requires expert processing.
- Resource managers must evaluate usefulness of the integrated bathymetry product.
- Provided the product is useful, the level of effort (including costs) required to derive bathymetry from satellite data is likely much less than to obtain the information via further SONAR or LIDAR surveys.

References

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Stumpf RP, Holderied K, Sinclair M (2003) Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnol Oceanogr 48:547-556