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Correlation scales of digital elevation models in developed coastal environments

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ABSTRACT

Accuracy of digital elevation models (DEMs) often depends on how features of different spatial scales are represented. Scale dependence is particularly important in low gradient coastal environments where small vertical errors can affect large areas and where representation of fine scale topographic features can influence how DEMs are used for modeling inundation. It is commonly observed that different types of DEMs represent larger, coarse-scale topographic features similarly but differ in how they represent smaller, finer-scale features. The spatial-scale dependence of DEM accuracy can be quantified in terms of the correlation scale (λ_C); the spatial wavelength above which models agree with spectral coherency >0.5 and below which they differ. We compare cross spectral analyses of the GDEM2 and SRTM global DEMs with 14,572 LiDAR-derived elevations along transects in diverse coastal environments of New York City. Both global DEMs have positive bias relative to LiDAR ground elevations, but bias (μ) and uncertainty (σ) of GDEM2 (μ: 8.1 m; σ: 7.6 m) are significantly greater than those of SRTM (μ: 1.9 m; σ: 3.6 m). Cross-spectral coherency between GDEM2 and the LiDAR DEM begins to roll-off at scales of $\lambda < \sim 3$ km, while coherency between SRTM and the LiDAR DEM begins to roll-off at scales of $\lambda < \sim 1$ km. The correlation scale below which coherency with LiDAR attains a signal to noise ratio of 1 is ~1 km for GDEM2 and ~0.5 km for SRTM; closely matching the divergence scales where the surface roughness of the land cover exceeds the roughness of the underlying terrain.

1. Introduction

Hazard assessments and inundation modeling of coastal areas rely heavily on both the accuracy and resolution of digital elevation models (DEMs). In many coastal areas, global DEMs offer the most complete representation of coastal elevations and morphology available. Two distinct classes of global DEM are currently in widespread use: passive source stereographic models derived from optical imagery like the ASTER GDEM2 (Abrams et al., 2010) and active source ranging models derived from synthetic aperture radar like the SRTM (Farr et al., 2007). The accuracy of each model depends on multiple factors related to the sensing modality, the procedure used to estimate elevations, and the characteristics of the land surface (Farr et al., 2007; Lang & Welch, 1999). The recent release of full-resolution 30 m SRTM data for areas outside the US (previously degraded to 90 m) prompts the question of how the accuracy and effective spatial resolution of SRTM and GDEM2 compare, particularly in developed coastal environments where they may be used for inundation modeling and hazard assessments.

The accuracy and resolution of DEMs in coastal environments, where there are relatively small differences in elevation over large areas, are of special interest. At low elevations and gradients the signal magnitude approaches the noise level of the measurements, which can lead to large errors in inundation extent forecasts. This issue is particularly important for developed coastal environments where the spatial extent of inundation can have disproportionate consequences in terms of loss of life and property. There have been several comparative analyses of global DEM vertical accuracy (e.g., Gesch et al., 2012; Meyer et al., 2012; Tachikawa et al., 2011; Tadono et al., 2012; Smith & Sandwell, 2003). Some analyses have included coastal areas (e.g., (Gorokhovich & Voustianiouk, 2006; Hvidegaard et al., 2012), and some have incorporated land cover/use information (e.g., Gesch et al., 2012; Hofton et al., 2006; Carabajal & Harding, 2006), but we are not aware of any that specifically consider the accuracy and spatial resolution of global DEMs in developed coastal environments. As explained below, the scale and diversity of land cover in developed coastal areas is fundamentally different from most of the environments where previous studies have focused.

The objective of this analysis is to assess the accuracy and scale dependence of the GDEM2 and SRTM global DEMs in developed coastal environments. We address the issue by quantifying the scale dependence of the agreement between these global DEMs and high-

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accuracy, high-resolution, LiDAR-derived elevations for a diverse variety of coastal environments within New York City (NYC). We quantify the scale dependence by using cross-spectral analysis to estimate the correlation scale (the length scale below which two signals are uncorrelated) of each global DEM with a co-registered DEM and digital surface model (DSM) derived from LiDAR. The LiDAR DEM (LDEM) and DSM (LDSM) have been thoroughly validated throughout the study area and thus provide high-quality benchmarks for the analysis. We focus on quantifying the lateral length-scale at which the agreement between two models becomes random. This is complementary to, but distinct from, previous studies that used point-to-point comparisons (e.g., GPS or fiducial) to measure the absolute accuracy of the global DEMs. To our knowledge, the only scale-dependent analyses of global DEMs are those of (Smith & Sandwell, 2003; and Rodriguez et al., 2006) but neither focus on developed or coastal environments.

2. Data

The geological and geomorphic diversity of NYC includes a wide range of developed and natural coastal environments and land

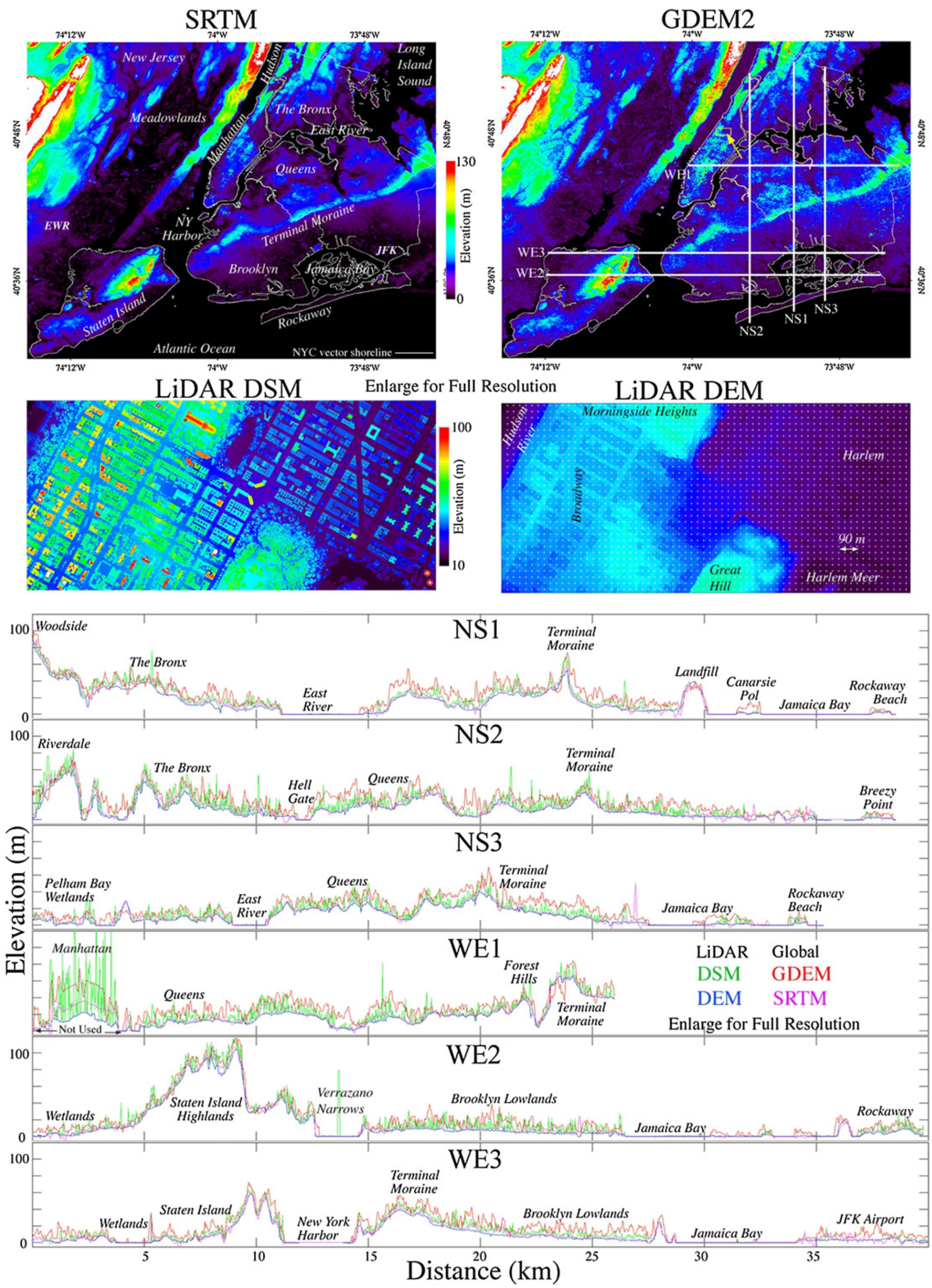

Fig. 1. Comparison of global elevation models (top) with full-resolution samples of the LiDAR DSM and DEM (center) and coregistered profiles from each model used for analysis. Location of LiDAR sample shown by arrow and box on GDEM2 map.