Examining Lidar in Remote Sensing: The concepts behind Lidar and examples of its many applications

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Abstract

Lidar has many applications in remote sensing. It is used to monitor atmospheric conditions including the composition, temperature, concentration and wind speed of aerosols. Airbourne lidar is able to generate accurate and extensive digital elevation models (DEMs) which allow for mapping of the sea floor as well as coastal, urban, and forest environments. Studies in these environments can be greatly aided by the addition of accurate elevation data. This paper will explain the general concepts behind different lidar systems and show examples of their use.

Introduction

Lidar was conceived shortly after lasers were first developed. As the many uses for radar where being realized in the late 1950s and early 1960s it seemed logical to use lasers in a similar fashion. By the mid-1980s lidar systems were developed that could detect atmospheric aerosols. These systems have undergone many changes since then. Their usefulness has increased as the technology behind lasers advances in a broad number of areas such as telecommunications. Lidar gained more attention in 1994 when NASA conducted the Clementine project that included the mapping of the moon using a lidar system aboard a spacecraft.

When people think of lidar today, it is usually in reference to airbourne platforms. These systems followed the development of Global Positioning Systems (GPS) and Inertial Reference Systems (INS). Airbourne lidar has allowed for the gathering of accurate elevation data which alone has many uses. Stationary and airbourne lidar systems will be further explored as will applications of these technologies.

Lidar for Atmospheric Monitoring

When a laser beam is sent into the atmosphere, it is scattered by the same mechanisms affecting optical multispectral systems – namely Rayleigh and Mie scattering. This scattering occurs because the wavelength of the laser beams is often in the UV or visible range. The amount of scattering reveals the concentrations of different atmospheric constitutes. Lidar systems send pulsed beams of laser light into the atmosphere and record their return signal. The time it takes for a signal to return determines the distance of atmospheric constitutes while the strength of the return signal indicates their concentration.

Currently the most advanced systems are able to determine the composition of atmospheric constitutes. Pollutants absorb electromagnetic radiation (EMR) in specific areas of the electromagnetic spectrum depending on their composition. Differential Absorption Lidar (DIAL) emits two laser beams with wavelengths close to each other. If a return signal is recorded from one beam and not the other, both the composition and location of an atmospheric constitute can be determined (Ulrich, 1998; Molero & Jaque, 1999; Thomasson, et al., 2001).

Information can also be gained from the phase of the return signal. Changes in phase can be attributed to temperature and velocity (Wiegner, et al., 1999; Thomasson, et al., 2001). By combining all the data gathered by lidar systems, 3-dimensional (3D) maps can be created that include a wide range of atmospheric data (Thomasson, et al., 2001).

Lidar networks have existed for many years with the purpose of gaining knowledge of the dynamics around atmospheric aerosols which are an important component of the radiation field and water cycle (Wiegner, et al., 1999). Sakai, et al (2002) used such a network to record a dust storm event in eastern Asia (Figure 1). Dust storms from this region affect the climatic and biogeochemical system in the Asia-Pacific region by changing the radiation balance and acting as cloud nuclei (Sakai, et al., 2002). Monitoring of pollution sources is also possible with lidar. Information can be gained on the concentration of pollutants as well as their distribution over time and space (Molero & Jaque, 1999).

Airbourne Lidar

The principles behind airbourne lidar do not differ markedly from atmospheric-based lidar in that pulsed laser beams are emitted and their return signal is recorded. Airbourne systems however, must be integrated with GPS and INS to provide georeferenced data. The GPS provides highly accurate geographical locations while the INS accounts for the roll, pitch and heading of the aircraft. The resulting data set is referred to as a Digital Surface Model (DSM) which is essentially the collection of return signals over a discrete space. Very accurate DEMs can be derived from the DSM using various interpolating methods.

Digital elevation models can be used in many more applications than can be listed here. Priestnall, et al. (2000) used a DSM to not only create an accurate DEM but to derive a surface roughness layer, which through classification techniques, was able to discern between buildings and trees. The project was able to forecast flood hazard areas with the DEM as well as identify areas of higher urban concentrations with the building layer.

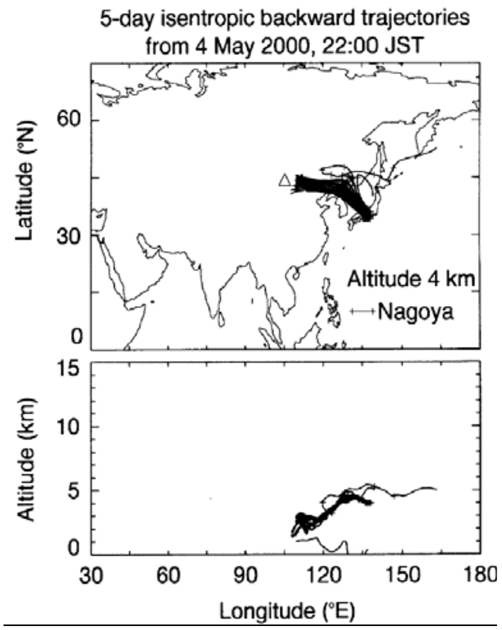

Figure 1. 3D map of a dust storm event (Sakai, et al., 2002).

Adding a temporal aspect to DEMs increases their usefulness in geomorphologic studies. The coastal zone in particular has many processes that occur in short time periods and have large impacts on the human population. Beach and dune areas were studied by Woolard & Colby (2002) who showed large differences could occur in the volume of these areas in a short time. Similarly, White, et al. (2002) used DEMs to map morphologic change in the North Carolina coastline. Comparing differences in the DEMs showed how recent storms affected the coastline. This method was able to identify the effectiveness of different coastal engineering strategies.

Ocean Applications

Lidar’s range also extends under the ocean’s surface. These systems use shorter wavelengths that better penetrate water. Return signals are collected from reflection of the sea surface and sea floor. The return decreases with depth and varies greatly with turbidity – the effective depth is typically three times the visible depth (Irish & Lillycrop, 1999). This technology has allowed for extensive and accurate bathymetry which is important in busy shipping and fishing areas.

Return signals are also collected from objects within the water. The Fish Lidar Oceanic Experimental (FLOE) system was constructed in the early 1990s and has been shown to effectively detect sardines and other fish (Brown, et al., 2002). Fish eggs have also been detected and quantified by lidar data (Ulrich, 1998).

Canopy Height

As Lidar can collect data on both sea floor and sea surface, it can do the same for canopy height and ground surface. In building a DEM, returns from the ground surface can be used exclusively to more accurately represent topography. Such DEMs have helped identify ground faults that were previously hidden (PSLC, 2002). Perhaps more importantly, this type of data can be used to map forest coverage which could be useful for forest management as well as climate-change models. These models rely on the amount of carbon present in forests to predict future carbon dioxide levels.

Estimates of biomass were not possible with early airbourne lidar system. These systems are typically flown at low altitudes and use a small beam or footprint. Often these systems only record the highest and lowest return signal which does not allow for the determination of density. Newer lidar systems, known as large-footprint lidar, are flown at higher altitudes, have a larger beam size, and collect the entire return signal over time. This return information is known as a waveform and provides density from the top of the canopy to the ground surface (Figure 2).

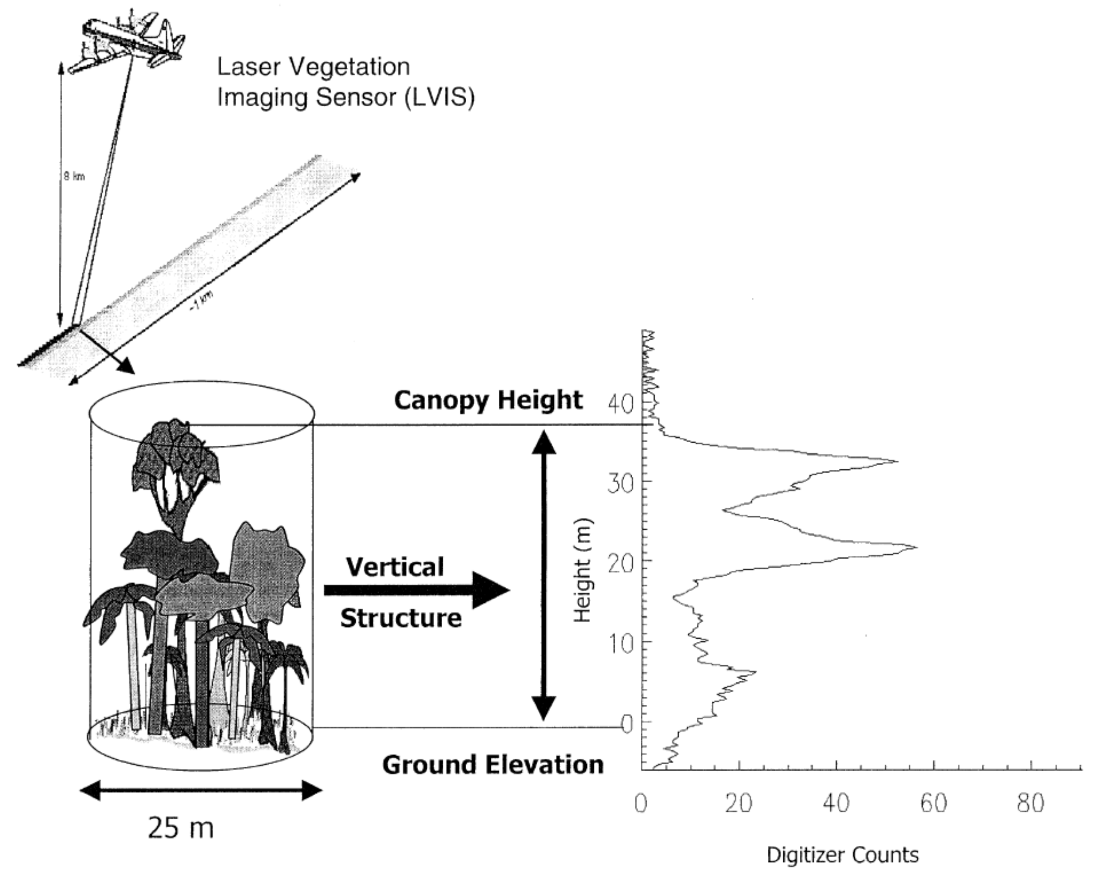

Figure 2. Schematic of the LVIS waveform as it relates to canopy density (Drake, et al., 2002).

The Laser Vegetation Imaging Sensor (LVIS) is one such large-footprint lidar system. This sensor is similar to the one aboard the Vegetation Canopy Lidar (VCL) mission which is planned to be launched in the near future. The LVIS has been used to validate the VCL mission through a number of studies. In order to judge the accuracy of the LVIS a number of indices have been developed. These include quadratic mean stem diameter (QMSD), basal area, and aboveground biomass (AGBM). Drake, et al. (2002b) compared these indices with field observations and found QMSD and AGBM to be 93% accurate with basal area at 72% accurate.

Similar validation of these indices has been done by Blair, et al. (1999), Lefsky, et al. (1999), Drake, et al. (2002a), and Hofton, et al. (2002). Lefsky, et al. (1999) also explore conceptual models that include zones of classification (Figure 3). Much anticipation now centres on spacebourne lidar systems. The VCL as well as the Ice, Cloud, and Land Elevation Satellite (ICESat) should provide valuable data about this planet in the near future.

Data Integration

Researchers are exploring ways of integrating lidar data with multispectral, optical data. Hudak, et al. (2002) for example, were able to correlate canopy height values with optical characteristics within Landsat ETM data. This allowed accurate classification of canopy heights where lidar data did not exist.

Canopy height data has also aided in the classification of hyperspectral data. Hyperspectral sensors such as the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) and the Compact Airborne Spectrographic Imager (CASI) have been shown to have problems classifying forested areas where bidirectional reflectance interfered with reflectance measurements in shaded areas of the canopy (Lobell et al., 2002). Blackburn (2002) used a DEM from lidar data to remove these areas from a CASI image based on their vertical structure. In effect, a classification was performed on specific portions of the canopy which lead to increased species differentiation.

Gamba, et al. (2002) found that using a variety of data sourced helped increase classification accuracy in urban areas. Lidar data was combined with an aerial photograph and Side Aperture Radar (SAR) image to produce a land cover map. Digital Terrain Models (DTM) where also generated from both lidar and Interferometric Synthetic Aperture Radar (InSAR) data. Through these DTMs, it was possible to extract

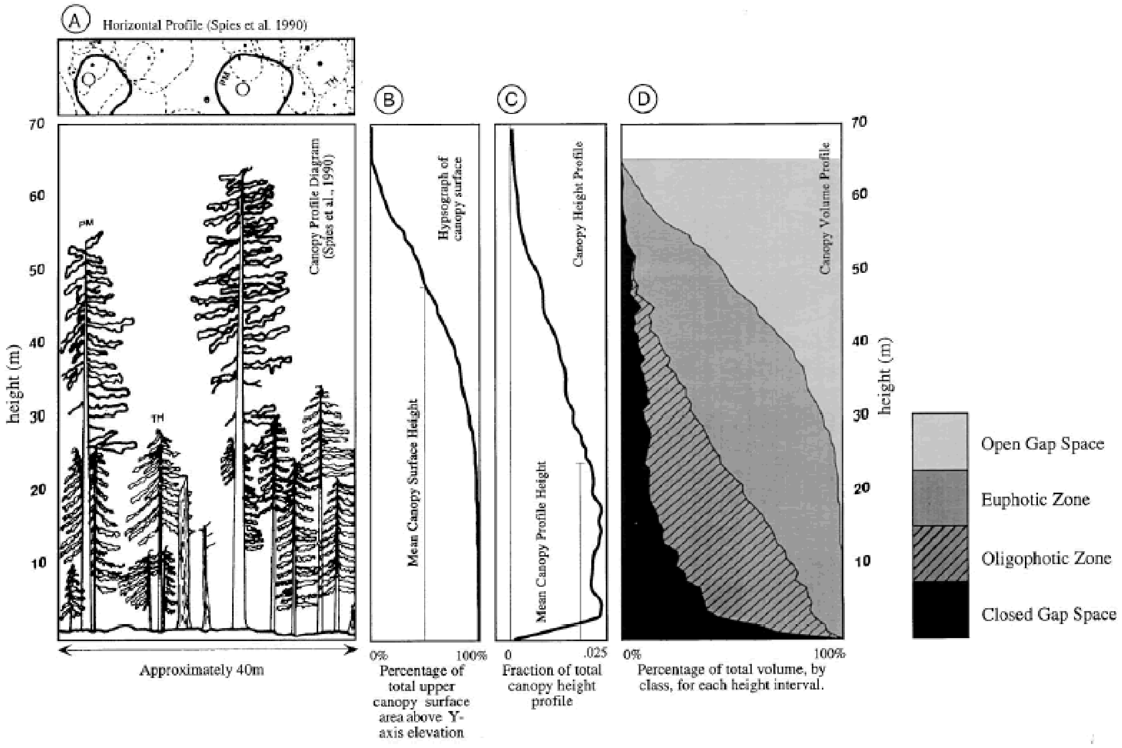

Figure 3. Using waveforms to classify canopy density (Lefsky, et al., 1999).

vectors of 3D buildings (Figure 4). Remote sensing of building could allow for extensive and inexpensive measures of urban sprawl over time, as well as aid in urban management.

Fluorescence Lidar

Lidar can also function similarly to optical, multipectral remote sensing. This is accomplished by emitting laser beams of various wavelengths and recording their return intensities. In this way spectra can be collected on various objects – these spectra can then be cataloged and used to identify unknown objects. This method has been successfully performed on oil spills and algae which is an important indicator of overall marine activity (Ulrich, 1998).

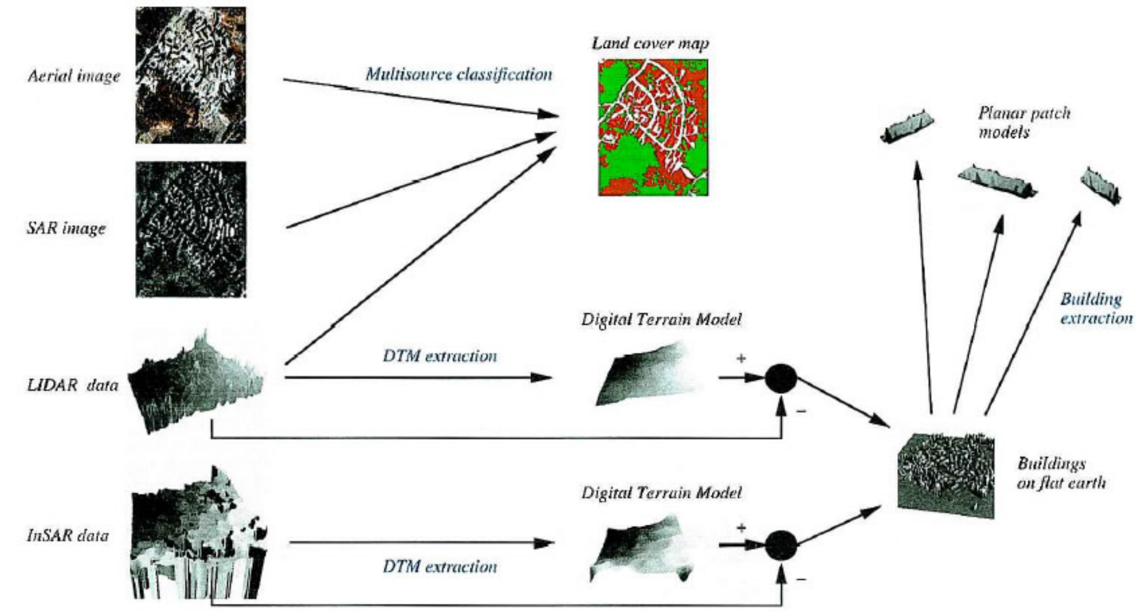

Figure 4. Integration of data sets for classification and vector extraction (Gamba, et al., 2002).

Cecchia, et al. (1999) show that fluorescence lidar has very different uses. Fluorescence spectra were plotted for known stone types and bacteria by a fluorescence lidar system located in a van. Using these spectra it was possible for fluorescence lidar to detect damaging bacteria in historic stone monuments before it was noticeable by human vision (Figure 5).

Conclusion

Lidar data has been used for many purposes and applications. These go beyond academic and management uses as shown by the tragedy of September 11. Lidar was used shortly after the destruction of the World Trade Centre to coordinate rescue efforts. DEMs were used in conjunction with architectural maps to determine the location of buried passageways (NOAA, 2001).

As lidar proves itself to be more and more useful, advances are constantly being made. The information resulting from lidar data has become much more precise and accurate in a very short time. The addition of large-footprint, satellite based systems will make lidar a leading sensor in the determination of the world’s biomass. Advances in fluorescence lidar will allow for the detection of much more than algae. Highly accurate DEMs are being integrated in many studies involving remote sensing and may one day become an essential component. The possibilities for the future of lidar make it an exciting technology indeed.

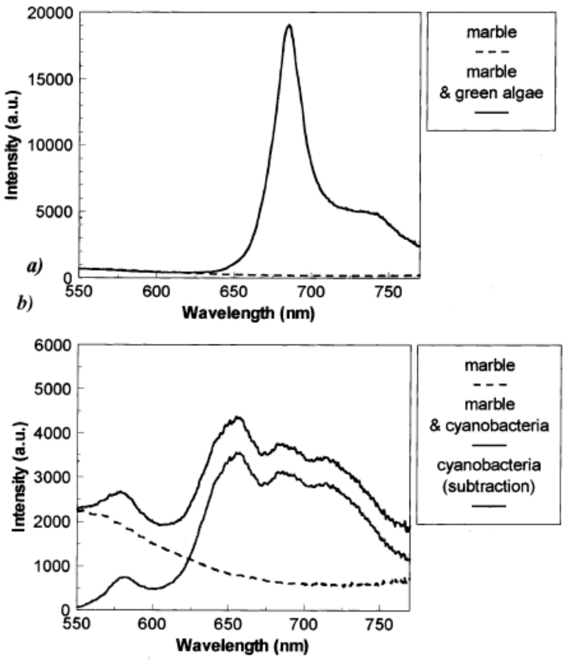

Figure 5. Example of fluorescence spectra used to monitor the health of historic monuments (Cecchia, et al., 1999).

References

Journals

Blackburn, G. 2002. Remote sensing of forest pigments using airborne imaging spectrometer and LIDAR imagery. Remote Sensing of Environment. 82, 311– 321.

Blair, J., Rabine, D., Hofton, M. 1999. The Laser Vegetation Imaging Sensor: a medium-altitude, digitisation-only, airborne laser altimeter for mapping vegetation and topography. Journal of Photogrammetry & Remote Sensing. 54, 115–122.

Brown, E., Churnside, J., Collins, R., Veenstra, T., Wilson, J., Abnett, K. 2002. Remote sensing of capelin and other biological features in the North Pacific using lidar and video technology. International Council for the Exploration of the Sea: Journal of Marine Science. 59, 1120–1130.

Cecchia, G., Pantania, L., Raimondia, V., Tomasellib, L., Lamentib, G., Tianoc, P., Chiarid, R. 1999. Fluorescence lidar technique for the remote sensing of stone monuments. Journal of Cultural Heritage. 1, 29–36.

Drake, J., Dubayah, R., Know, R., Clark, D., Blair, J. 2002a. Sensitivity of large-footprint lidar to canopy structure and biomass in a neotropical rainforest. Remote Sensing of Environment. 81, 378– 392.

Drake, J., Dubayah, R., Clark, D., Knox, R., Blair, J., Hofton, M., Chazdon, R., Weishampel, J., Prince, S. 2002b. Estimation of tropical forest structural characteristics using large-footprint lidar. Remote Sensing of Environment. 79, 305– 319.

Gamba, P., Houshmand, B. 2002. Joint analysis of SAR, LIDAR and aerial imagery for simultaneous extraction of land cover, DTM and 3D shape of buildings. International Journal of Remote Sensing. 23 (20), 4439–4450.

Hudak, A., Lefsky, M., Cohen, W., Berterretche, M. 2002. Integration of lidar and Landsat ETM+ data for estimating and mapping forest canopy height. Remote Sensing of Environment. 82, 397–416.

Hofton, M., Rochio, L., Blair, J., Dubayah, R. 2002. Validation of Vegetation Canopy Lidar sub-canopy topography measurements for a dense tropical forest. Journal of Geodynamics. 34, 491–502.

Irish, J., Lillycrop, W. 1999. Scanning laser mapping of the coastal zone: the SHOALS system. Journal of Photogrammetry & Remote Sensing. 54, 123–129.

Lefsky, M., Cohen, W., Acker, S., Parker, G., Spies, T., Harding. 1999. Lidar Remote Sensing of the Canopy Structure and Biophysical Properties of Douglas-Fir Western Hemlock Forests. Remote Sensing of Environment. 70, 339–361.

Lobell, D., Asner, G., Law, B., Treuhaft, R. 2002. View angle effects on canopy reflectance and spectral mixture analysis of coniferous forests using AVIRIS. International Journal of Remote Sensing. 23 (11), 2247–2262.

Means, J., Acker, S., Harding, D., Blair, J., Lefsky, N., Cohen, W., Harmon, M., McKee, W. 1999. Use of Large-Footprint Scanning Airborne Lidar To Estimate Forest Stand Characteristics in the Western Cascades of Oregon. Remote Sensing of Environment. 67, 298-308.

Molero, F., Jaque, F. 1999. The laser as a tool in environmental problems. Optical Materials. 13, 167-173.

Priestnall, G., Jaafar, J., Duncan, A. 2000. Extracting urban features from LiDAR digital surface models. Computers, Environment and Urban Systems. 24, 65-78.

Sakai, T., Shibata, T., Iwasaka, Y., Nagai., Nakazato., Matsumura, T., Ichiki., Kim, Y., Tamura, K., Troshkin, D., Hamdi, S. 2002. Case study of Raman lidar measurements of Asian dust events in 2000 and 2001 at Nagoya and Tsukuba, Japan. Atmospheric Environment 36, 5479–5489.

Thomasson, A., Mondelain, D., Ménard, T., Nominé, M., Godet, Y., Wolf, J. 2001. Air pollution mapping using all solid-state Lidar systems. C.R. Acad. Sci. 7(IV), 923-929.

Ulrich, P. 1998. Laser remote sensing. Trends in Analytical Chemistry. 17 (8-9), 491-500.

White, S., Wang, Y. 2002. Utilizing DEMs derived from LIDAR data to analyze morphologic change in the North Carolina coastline. Remote Sensing of Environment. 5809, 1–9.

Wiegner, M., Bösenberg, J., Böckmann, C., Eixmann, R., Freudenthaler, V., Mattis, I., Trickl, T. 1999. Lidar Network to Establish An Aerosol Climatology. J. Aerosol Sci. 30 (1), 5429–5430.

Woolard, J., Colby, J. 2002. Spatial characterization, resolution, and volumetric change of coastal dunes using airborne LIDAR: Cape Hatteras, North Carolina. Geomorphology. 48, 269–287.

Internet

Puget Sound LIDAR Consortium (PSLC). 2002. Uses of lidar data. Retrieved February 28, 2003 from http://duff.geology.washington.edu/data/raster/lidar/faults/index.html

National Oceanic & Atmospheric Administration (NOAA). 2001. NOAA Remote Sensing Expertise Aids World Trade Center Recovery Efforts. Retrieved February 28, 2003 from http://www.noaanews.noaa.gov/stories/s781.htm
(NOAA, 2001)