GEO 428: DEMs from GPS, Imagery, & Lidar
Tuesday, September 11

Global Positioning Systems
GPS is a technology that provides
  Location coordinates
  Elevation
For any location with a decent view of the sky
Portable (on foot or in vehicle)
Price: Cheap → Extremely expensive
  Depending on accuracy requirements

GPS Components
Receiver (on ground, personal / in vehicle)
Transmitters (satellite constellation)
  32 satellites (http://tycho.usno.navy.mil/gpsev.html)
  12 hour orbits, 12,660 miles up
  onboard atomic clocks
  satellite positions known by receiver
Control Station
  Keeps clock time
  Communicates with satellites
  Changes their orbits

Satellites

Reading a Signal

What is the signal?
Satellite's location
Time of signal transmission
Almanac
  Orbital information (for all GPS satellites)
  Can be downloaded in advance of a survey
  Contains locational and band information so receiver 'knows' where satellites are
  Can be used to identify good and bad times of day for collection

Positioning
Satellite locations known exactly from almanac
By knowing exact distance from 1 satellite, we know we are on the surface of a sphere
With 2 we are on the edge of a circle
With 3 we are at one of two points on the circle

Elevation and GPS
Elevation can be measured; Requires more satellite fixes
Satellites must be relatively high overhead
Differential GPS has been used to resurvey Everest
Chinese Survey ('05): 29,017 ft
American GPS ('99): 29,035 ft
Indian Survey ('55): 29,028 ft
Indian Survey (1852): 29,003
Error Sources
Satellite not where we think it is (up to 4 m)
   Ephemeris error
   Clock off
Atmospheric distortion of signal (up to 5 m)
   Time delay is different than expected
Receiver-caused noise (up to .5 m)
Ground effects (multipath) (up to several m)

Positional Error Maps
Stand in one place and take many measures
   1-5 seconds each
Map result to gain insight
Perfect – all observations at one point
   Real world – some spread

Serial Correlation
Points taken close together in time
   Similar x, y, and height values
   Errors are also serially correlated
The longer you take (multiple) points, the better

Height Errors & Correlation
Experiment with WAAS on Garmin 76
   Regular undulating pattern

Differential GPS
By using a signal with known location, noise can be accounted for
   Error greatly reduced
Base station (w/ known location) receives signal simultaneously with the receiver
Discrepancies between GPS-location and true location at the base station can be identified
Discrepancy is ' differenced ' out of the receiver signal

WAAS DGPS
Wide Area Augmentation System
   Intended for aviation navigation (FAA)
Network of ground control stations
   28 stations across North America
   Closest are near Cleveland, OH and Chicago, IL
Transmitted to geostationary communication satellites
   Broadcast to enabled GPS units
   e.g. Magellan MobileMapper 6

WAAS and Positional Error
Experiment with WAAS on MobileMapper 6
   With WAAS: StdDev 0.3/0.6 m. (x & y)
   Without: StdDev 1.4/1.4 m.
WAAS and Vertical Error
Experiment with WAAS on Garmin 76
'Actual': 849 ft +- 2 ft
With WAAS: Mean: 858 ft StdDev 10 ft Range 843-875 ft
Without: Mean: 855 ft StdDev 21 ft Range 809-886 ft

Accuracy & Collection
Extremely approximate numbers!
Non-differential:
  2 – 10 meters in location
  5 - 30 meters in altitude
With differential, accuracy improves
  1-2 meter horizontal, 2-5 vertical
Elevation error may be biased in some receivers
  Related to satellite configuration

Tricks to improve accuracy
Point Averaging
  Collect multiple points at a location
  Average values over a couple of minutes (or more)
Conduct postprocessing to remove bad values

What do we do with the GPS points?
To make a DEM, one could
  Import them as (x,y,z) pairs and interpolate to grid
  Generate a TIN, then convert
  Use them to 'pin down' a stereo image
  Then use photogrammetric methods to generate a DEM
  Tune in next time for more on these!

Aerial / RS Imagery
Elevation extracted from image pairs
Pairs needed with different camera angles
Correlations between pixel values in each image used to generate DEM

Example
MOMS images of a portion of western Austria
Forward & backward scanned images are registered &combined to make anaglyph image

Sources of Stereo Photogrammetry
Aerial Photography
  Film or print scanned to obtain digital copy
  Fiducial marks & flight metadata (altitude, pitch, etc)
  Image can be orthorectified and draped over DEM
Ikonos / Quickbird Satellite imagery
  Require good ground control points (GCP)
  3-5 meter resolution possible, very low errors
SPOT-PAN
  Stereo Images taken on different orbits
The closer in time the better
20 or 40 m resolution

RADARSAT
Stereo synthetic aperture radar (SAR)
Radar 'bounce' recorded at multiple places

ASTER
EOS sensor used for lots of things
It can change viewing angles, making high resolution (15-30 m) stereo image pairs possible

SPOT-PAN Example
Time 1 is Red
Time 2 is Blue
It's a stereopair!
Angular difference between images

ASTER: Jordan Valley DEM
Dark blobs are cloud-covered, other noderata areas

Characteristics of these DEMs
May be sensitive to vegetation cover, clouds
Some have large and biased errors
Can be very high spatial resolution (sub meter)
Can capture temporal change

Combining Approaches
Using GPS ground survey in conjunction with aerial photography stereo pairs can produce good results
Arbogast et al. work on Dunefields
Change detection: 1965-1987

LiDAR
Light Detection and Ranging
Use of laser (directed light) to determine distance
Light emitted from laser
Some returns to the sensor
Time lag indicates distance
Used for decades for many things
eg atmospheric work

Elevations from Lidar
Aircraft mounted sensors:
laser
GPS (sensor location)
laser detection – rangefinder
Inertial Navigation System
Tilt, roll of aircraft
Swaths of points collected
Bounce off ground, trees, buildings, ...
Lidar Points
Gazoodles of points (x,y,z)
Postprocessing to thin and interpolate to raster
  Point removal
  Manual / Automated editing
  Breakline Insertion
  Interpolation
  QA/QC

Campus Lidar
April 2010 for Tri-County Area
Central Campus (5000 x 5000 ft):
  3.3 million returns

Lidar Derived Surfaces
Not bare surface!
“Last Returns”
  from ground
Multiple products
  Bare earth
  Canopy height
Proprietary Algorithms

Lidar Products
Building models
Raster DEMs/DSMs

Lidar Issues
Relatively Cheap
High Accuracy (cm)
Postprocessing is critical
We don't always want that much detail!
  Hydrologic modeling?
Present and Future of high resolution DEM production?

Remote DEMs
Some elevations still must be sensed remotely!
Radar and Optical Sensors, but no GPS

Summary
GPS
  Characteristics / Accuracy
  Differential
Stereo Imagery
  Production
  Sources / Characteristics
Lidar
  Sensors, characteristics