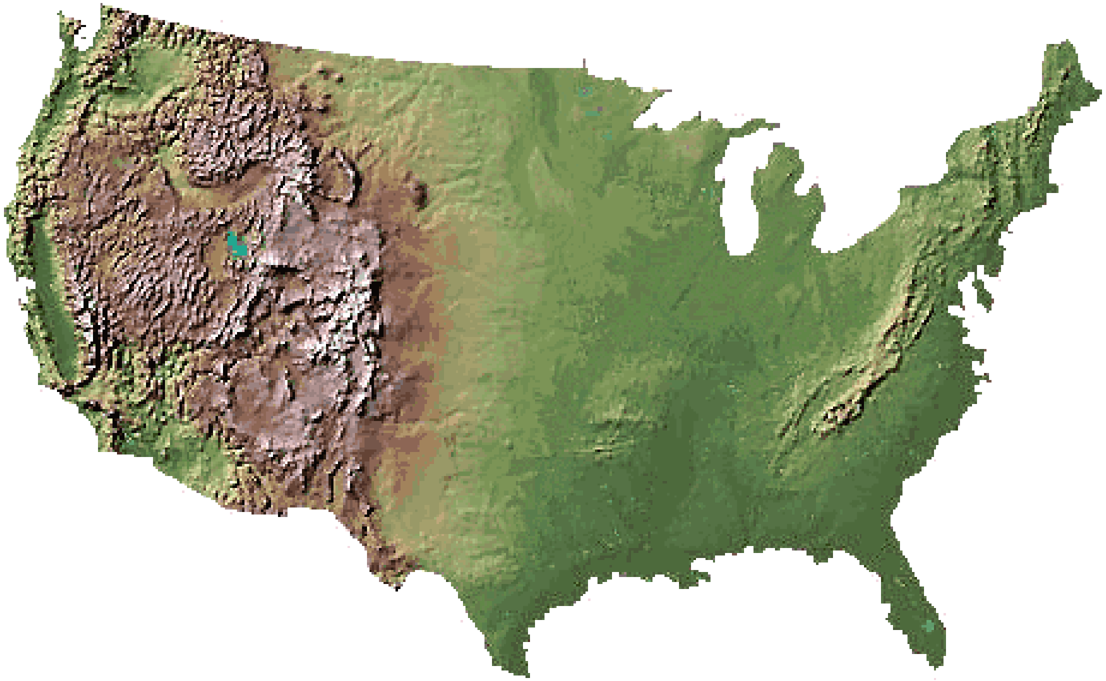
Digital Elevation Models



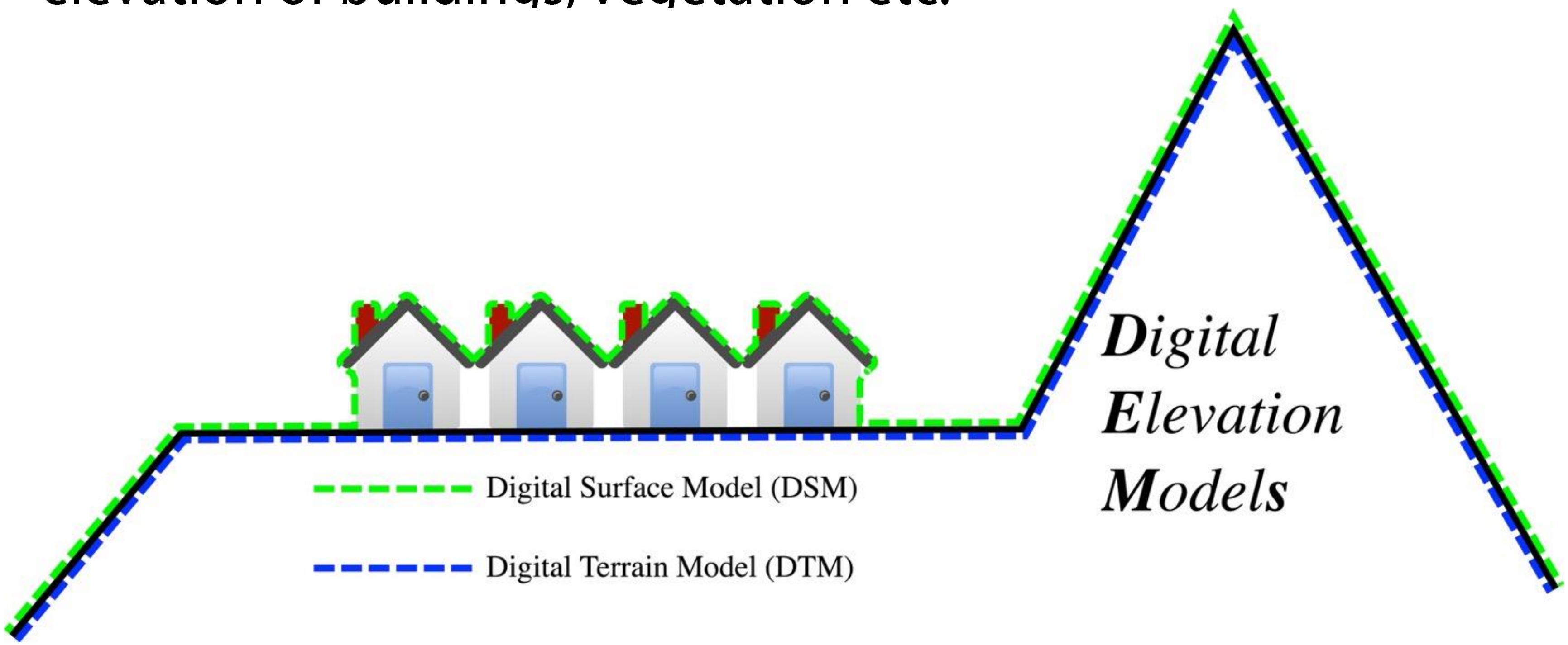
National Elevation Dataset

Commonly Used Data Sets

- US DEM series
  - 7.5’, 30’, 1° for conterminous US
  - 7.5’, 15’ for Alaska
- US National Elevation Data (NED)
- GTOPO30
- Global Land One-kilometer Base Elevation (GLOBE)
- ETOPO2
- Shuttle Radar Topographic Mission (SRTM)
- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)
- LIDAR data (TNRIS and other sources)
- Custom models from stereo photo pairs – photogrammetry – SfM-Structure from Motion
- Others – By permission or purchase

DEMs, DTMs, and DSMs

- DEM is a generic term for a topographic raster. Split into **digital terrain models (DTMs)**, which is the elevation of the ground surface, and **digital surface models (DSMs)**, which includes elevation of buildings, vegetation etc.



Courtesy of Dr. T. Goudge

How do we collect topography?

- ***Lots*** of ways to use topography data. ***How do we collect it?***
- Three common ways:
  - **InSAR:** Using interferometric synthetic aperture radar.
  - **Lidar (light detection and ranging):** Using an active sensor that bounces a laser off the surface and measures the time-of-flight to return.
  - **Stereogrammetry:** Using two visible images to match up surface disparity.
  - Digitizing (gridding) paper topographic maps

Courtesy of Dr. T. Goudge

US National Elevation Data (NED)

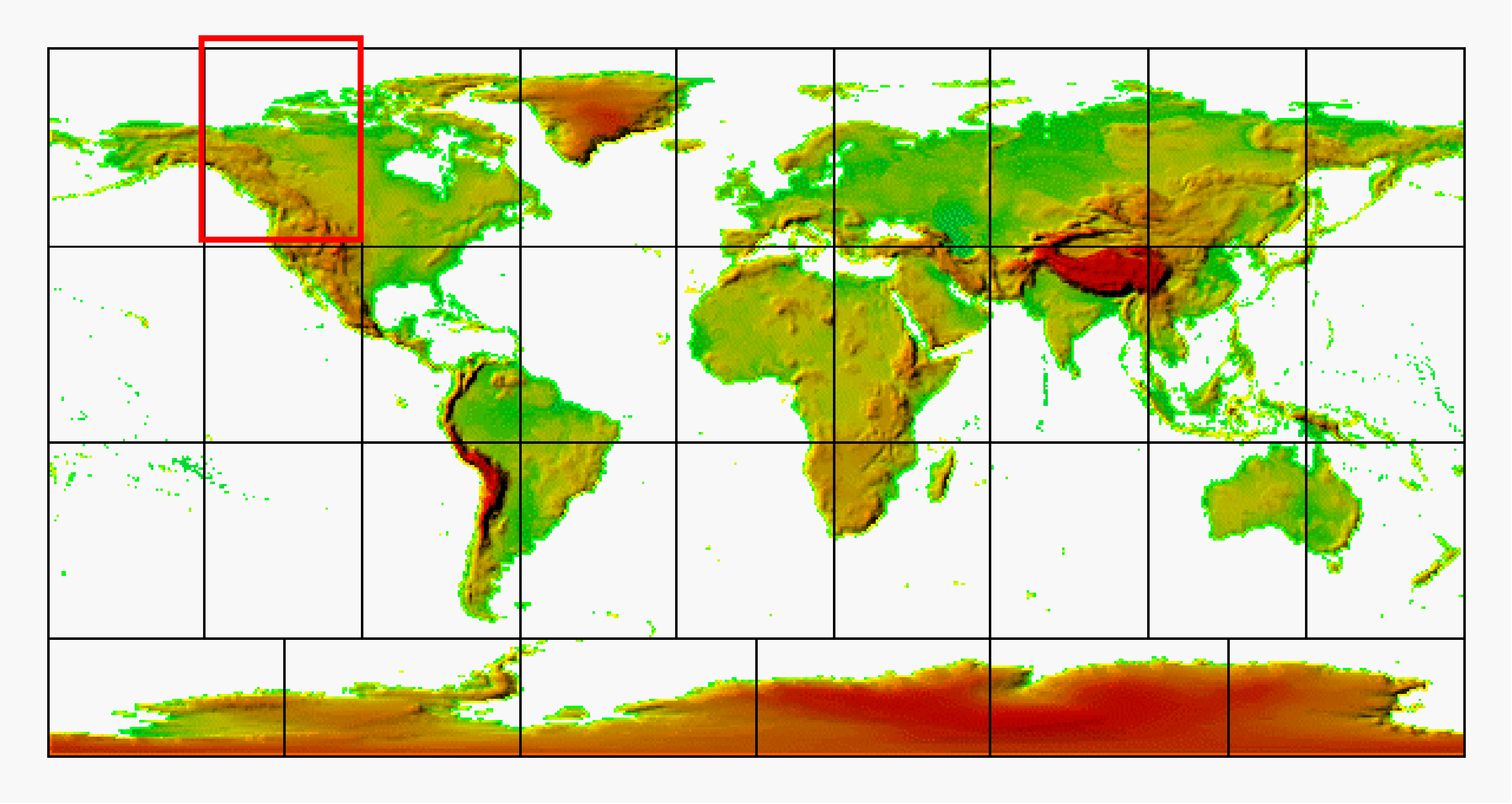
- Seamless data set for US and territories
- Stereophotogrammetry based
- 1, 1/3, 1/9 Arc Second (~30, 10, 3 m) resolution
- NAD83, decimal degrees
  - Distribution through National Map web site
  - Available in ESRI .grd format

GTOPO30

- USGS Global 30-Arc Second DEM
  - Completed 1996
  - Horizontal grid spacing ~ 1 km
    - 21,600 rows x 43,200 columns
  - WGS84 and “sea level” datums
  - Data are in decimal degrees and meters above S.L.

GTOPO30

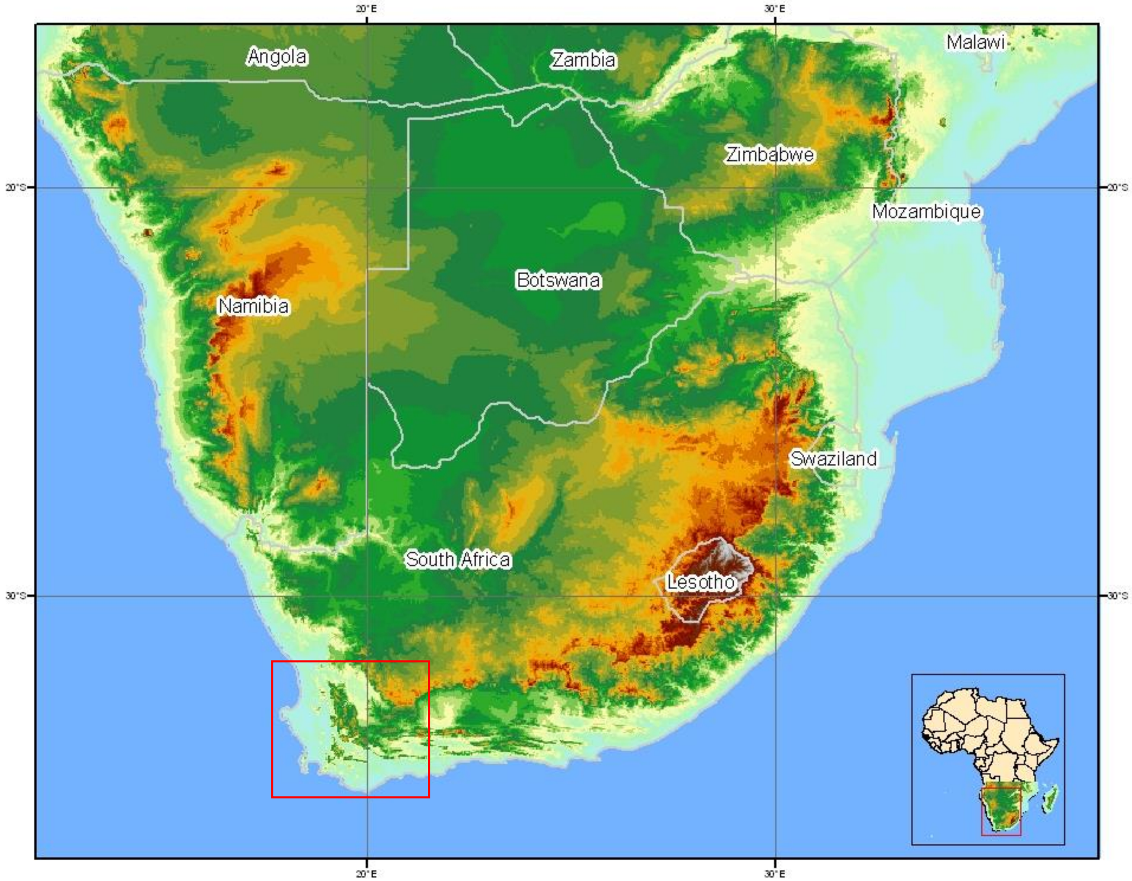
- 30º x 50º Data Tiles, EROS Data Center or via FTP



GTOPO30 in ArcMap

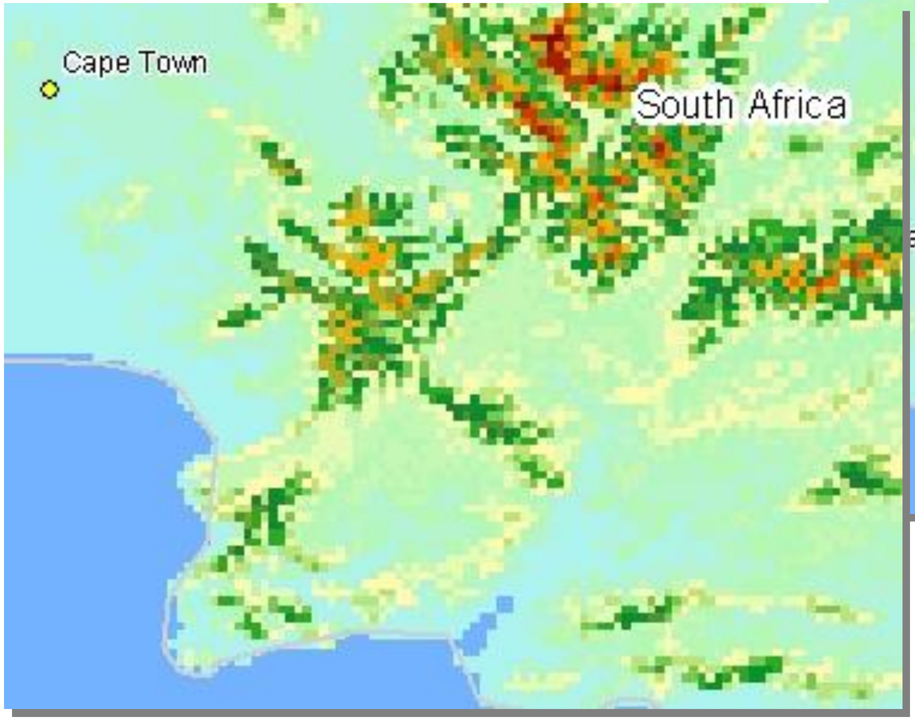
- Load in band-interleaved-by-line (.bil) format
- Convert .bil to .grd (Spatial Analyst)
    - 16 bit binary integer data converted to ASCII
- Use map calculator to restore negative values and convert –9999 (no data) cells to null.
- Details are available

GTOPO30 tiles in ArcMap

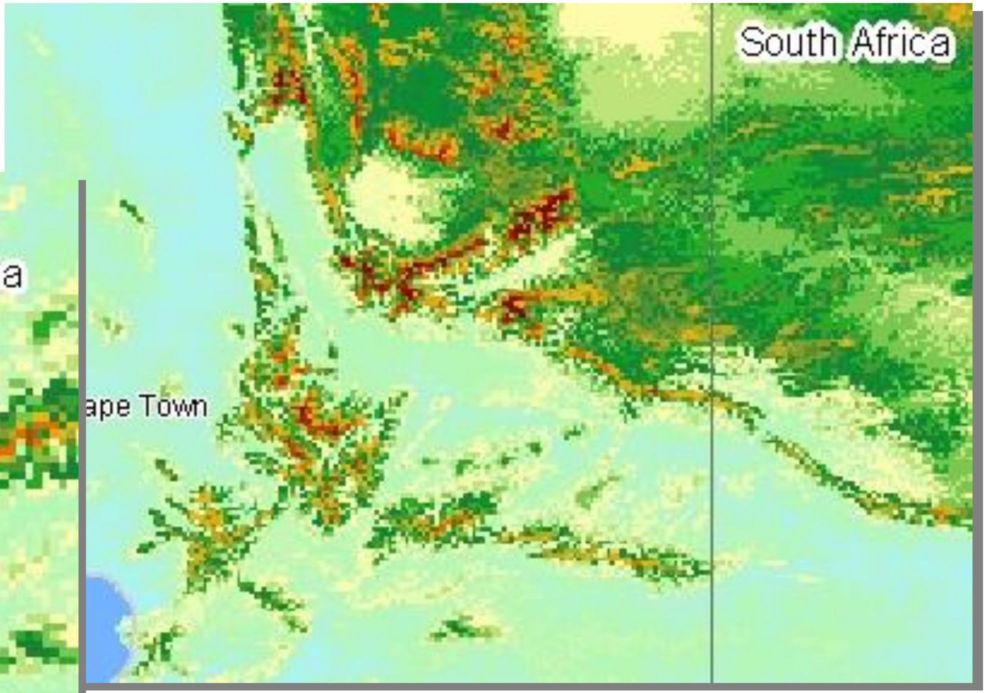


1:10,000,000 (as captured)
100 meter classes

GTOPO30 resolution: S. Africa



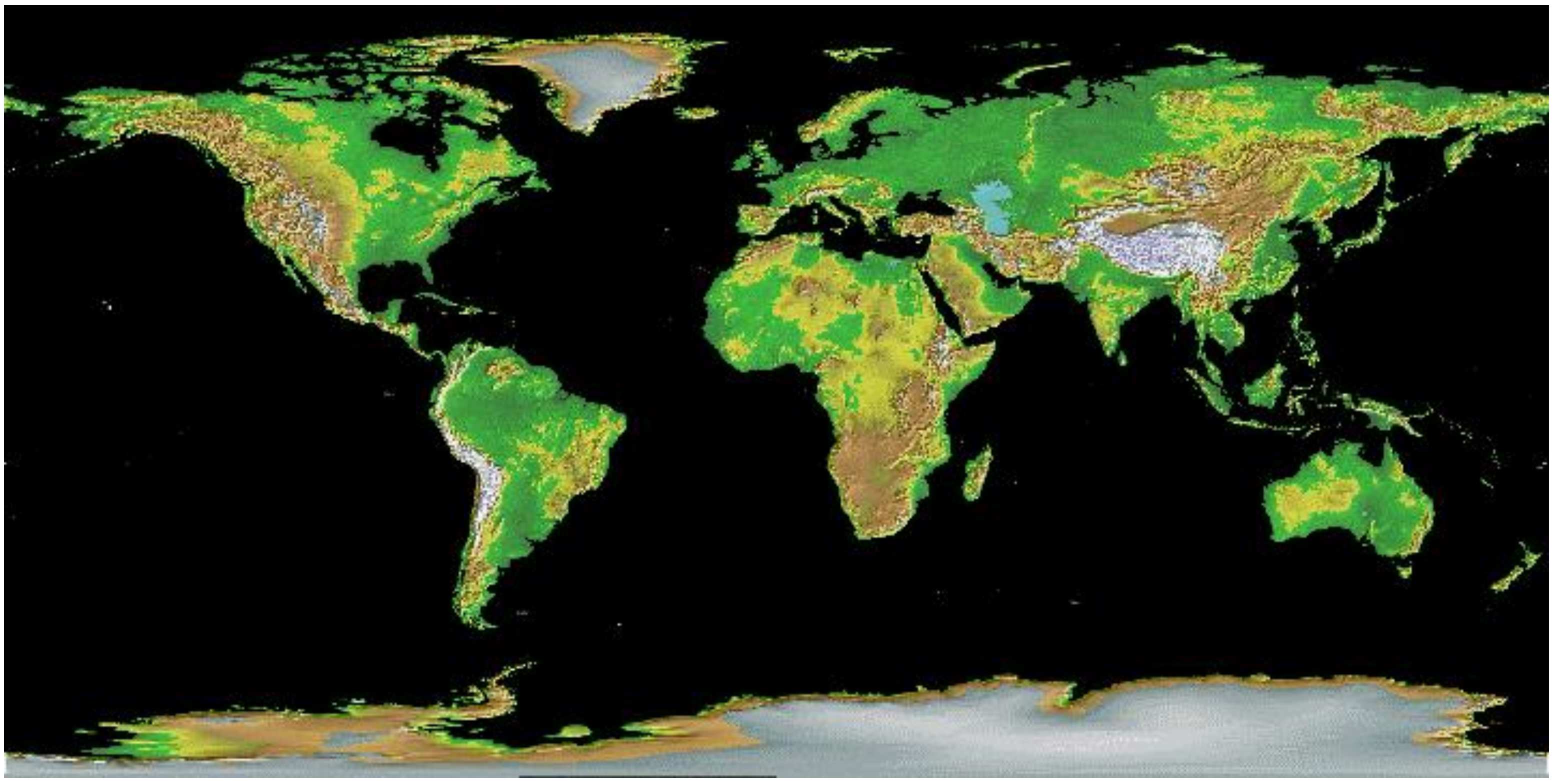
1:1,000,000



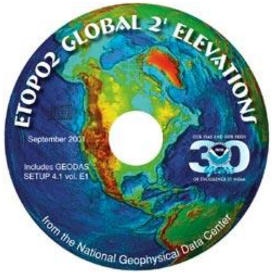
1:2,000,000

The *G*lobal *L*and *O*ne-km *B*ase *E*levation

- G.L.O.B.E. – NOAA data

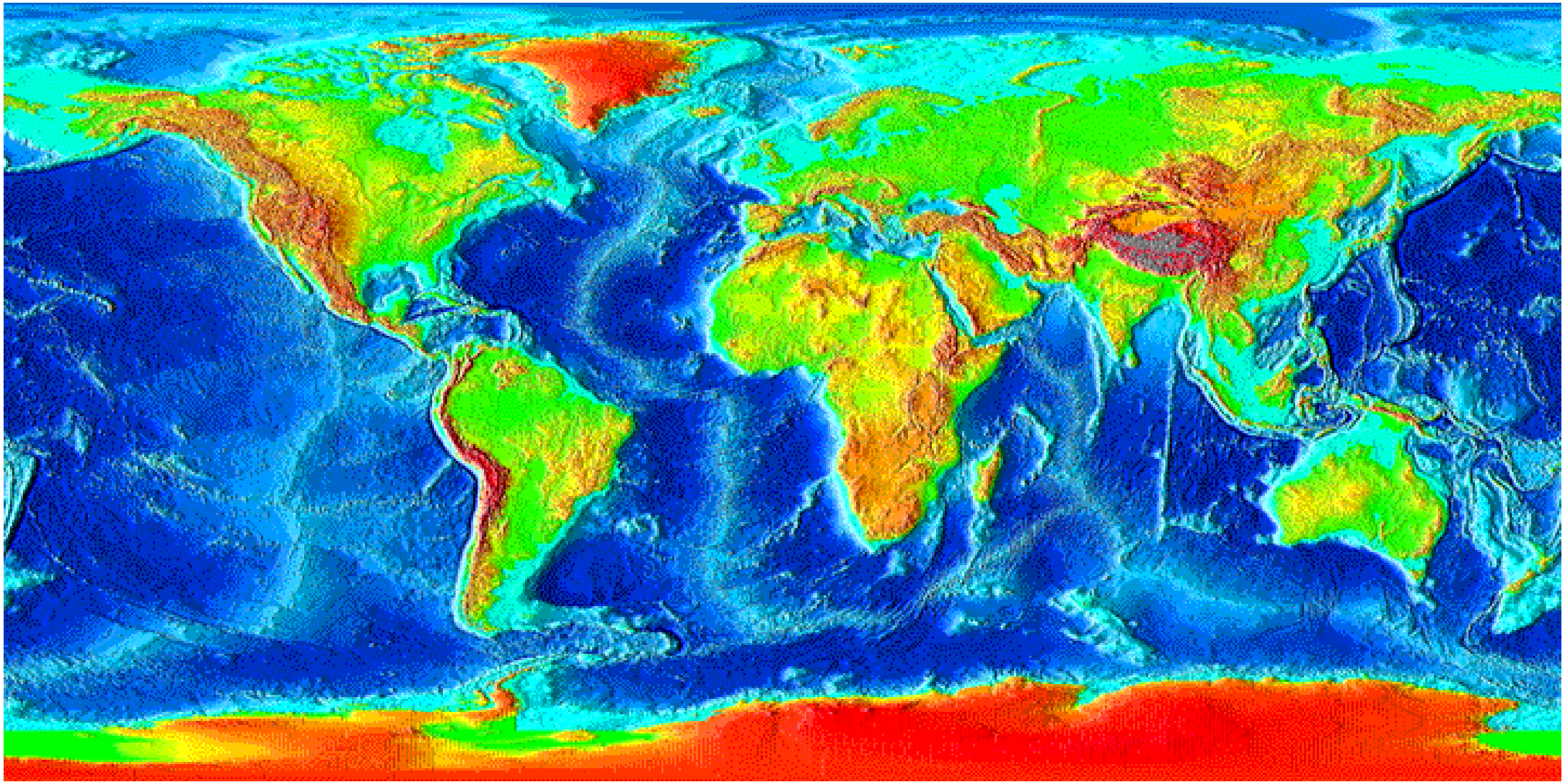


ETOPO2

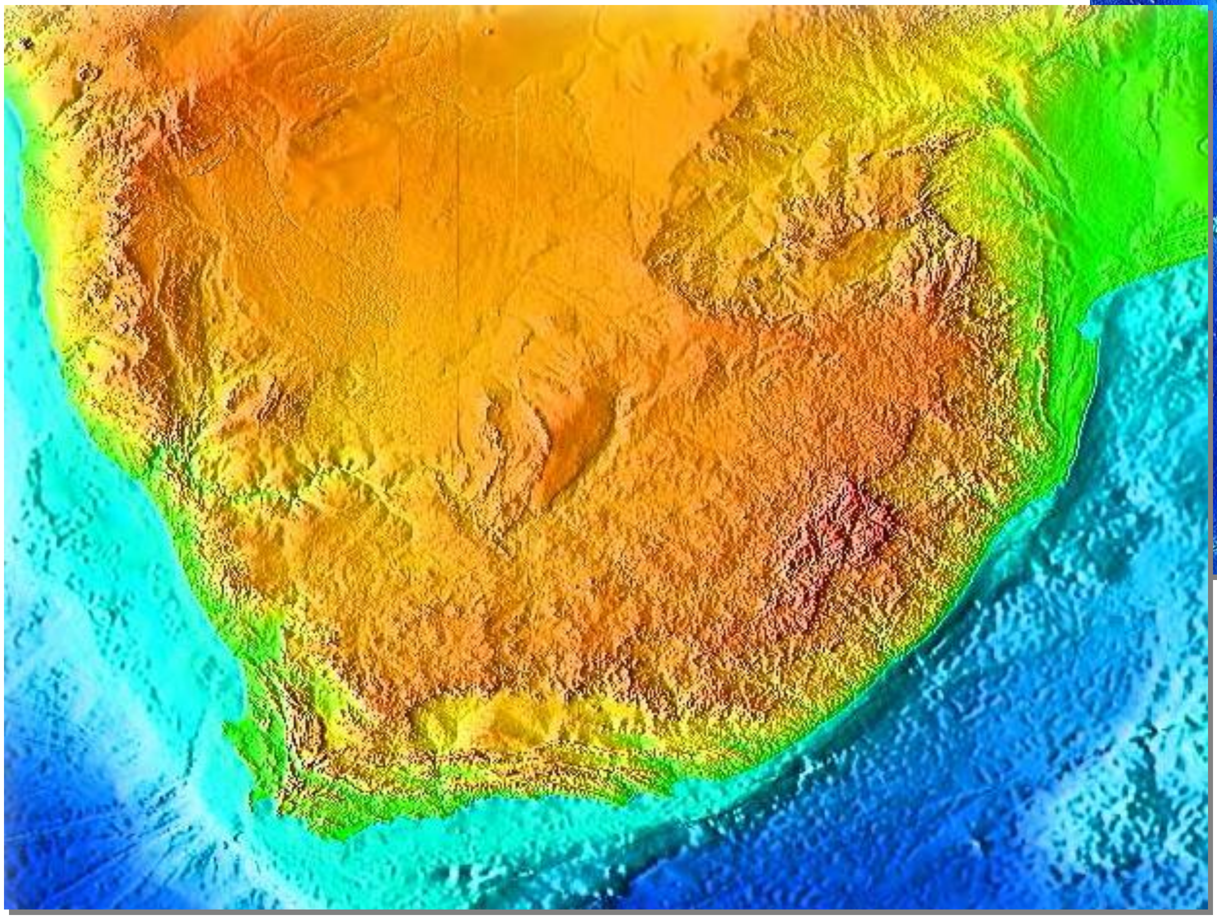


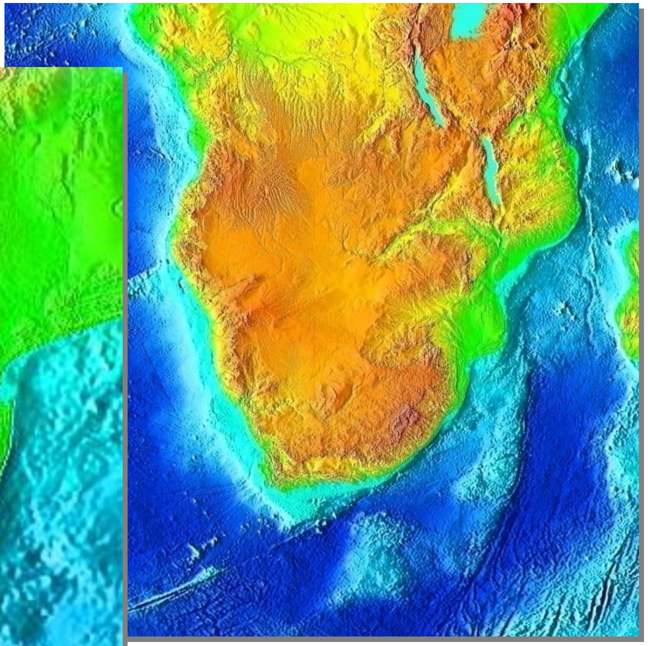
- NOAA global relief (land & oceans)
- Gridded at 2 minute resolution (~4 km): 10800 columns x 5400 rows
- Subsets can be extracted from CD in a variety of formats

ETOPO2

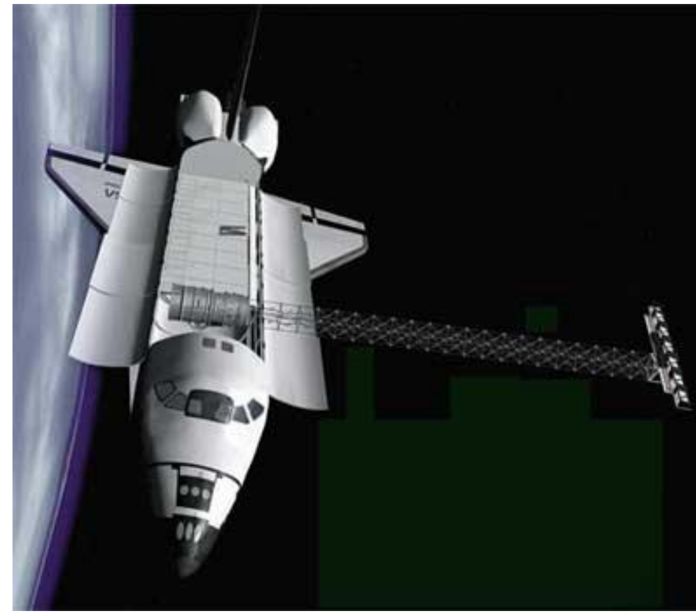


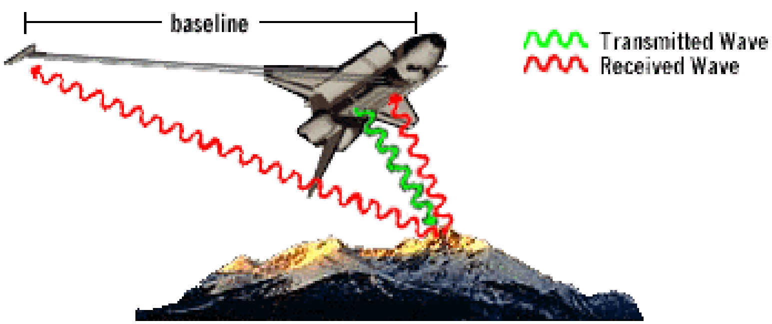
ETOPO2



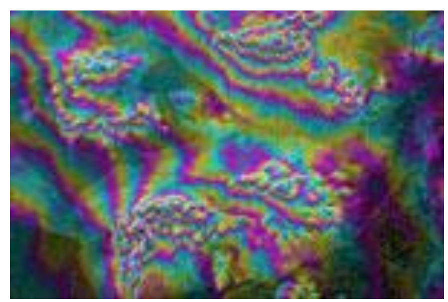


- 10-day mission in Feb. 2000 to map earth’s topography at 30 m x, y resolution and ~ 16 m in z
- *Topography derived from radar interferometry*
- One of two best global data sets to date





Radar signals being transmitted and recieved in the SRTM mission (image not to scale).

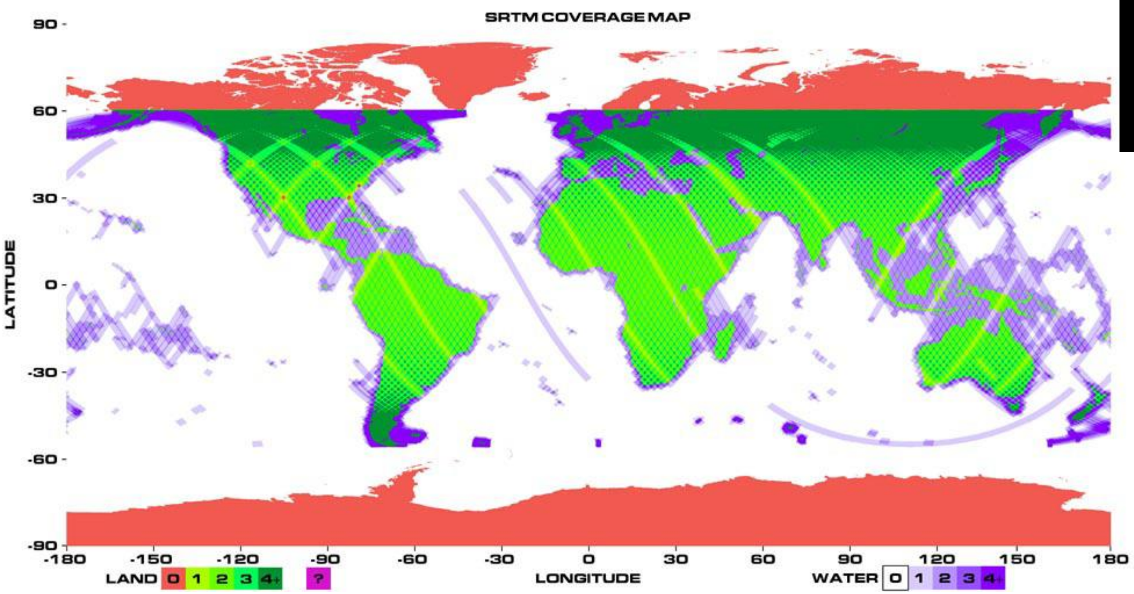


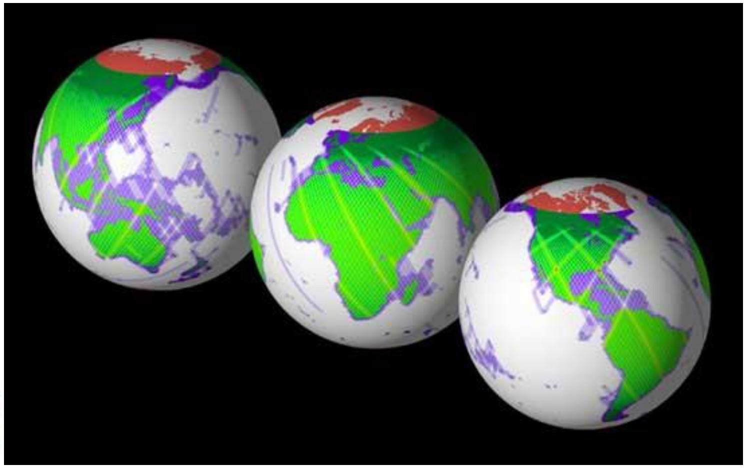
interferogram

Images courtesy of NASA
http://www.jpl.nasa.gov/srtm

SRTM Coverage

- ~ 60°N to 56°S latitude
- ~ 80% of land surface





Images courtesy of NASA
http://www.jpl.nasa.gov/srtm

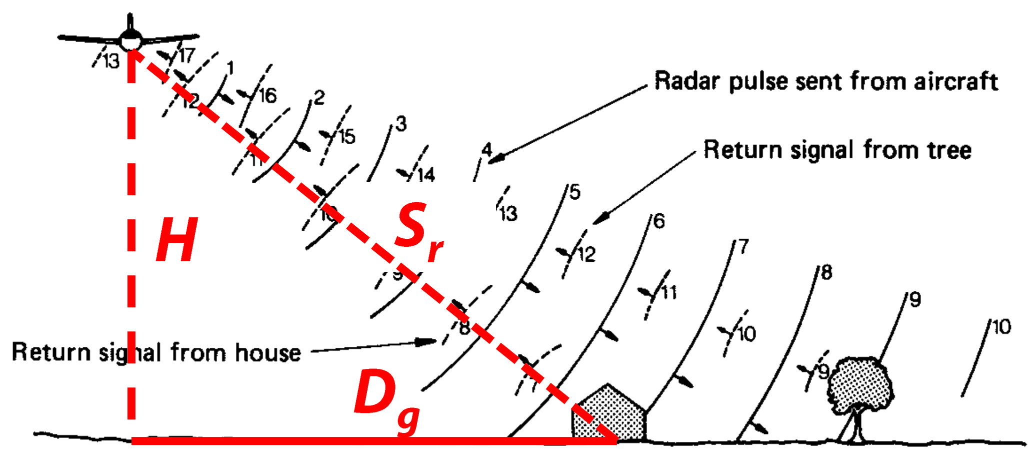
Imaging Radar

- Easily convert return time to distance (**range distance**, or sometimes **slant range; S_r**), since we know radiation travels at speed of light ($c = 3\text{x}10^8$ m/s).

- Can convert to **ground distance (D_g)** between object and line of flight using Pythagoras Thm. plus **platform altitude (H)**.

$$S_r^2 = H^2 + D_g^2$$

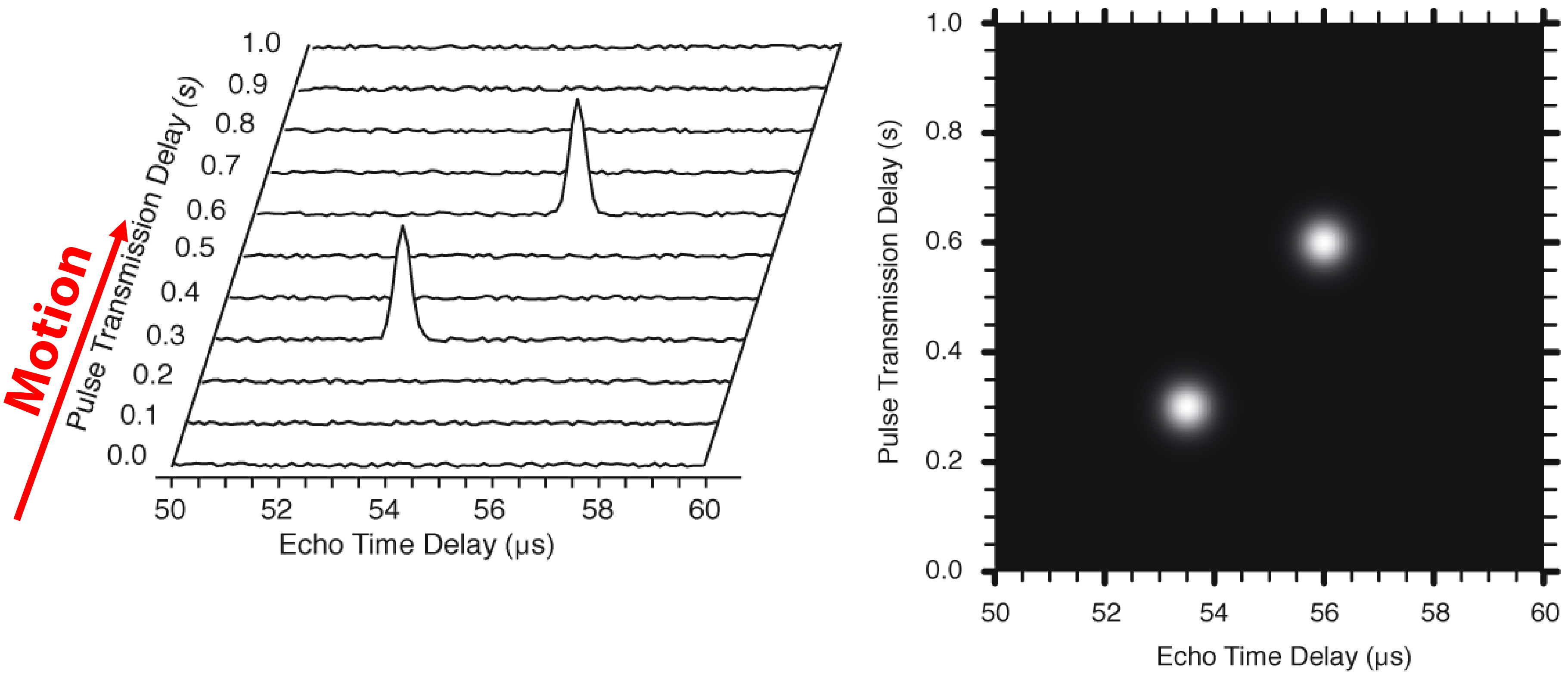
$$D_g = \sqrt{S_r^2 - H^2}$$



(a) Propagation of one radar pulse (indicating the wavefront location at time intervals 1-17)

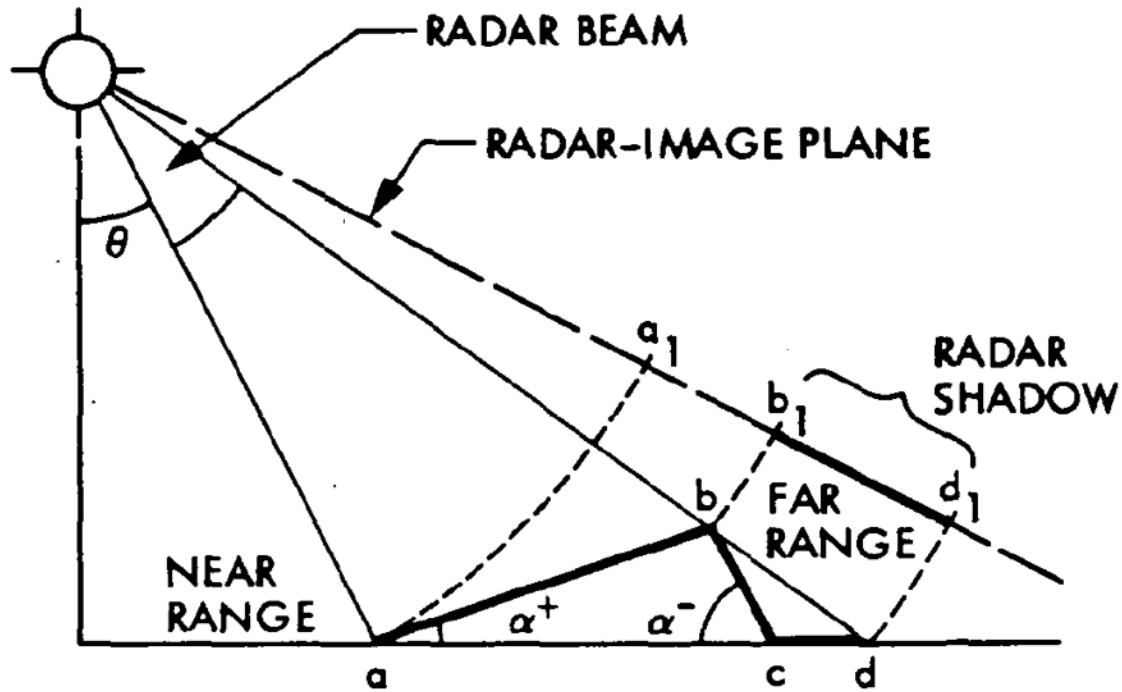
Imaging Radar

- Build up image across track with time delay of pulse, while platform motion builds pixels along track.



Radar Shadows

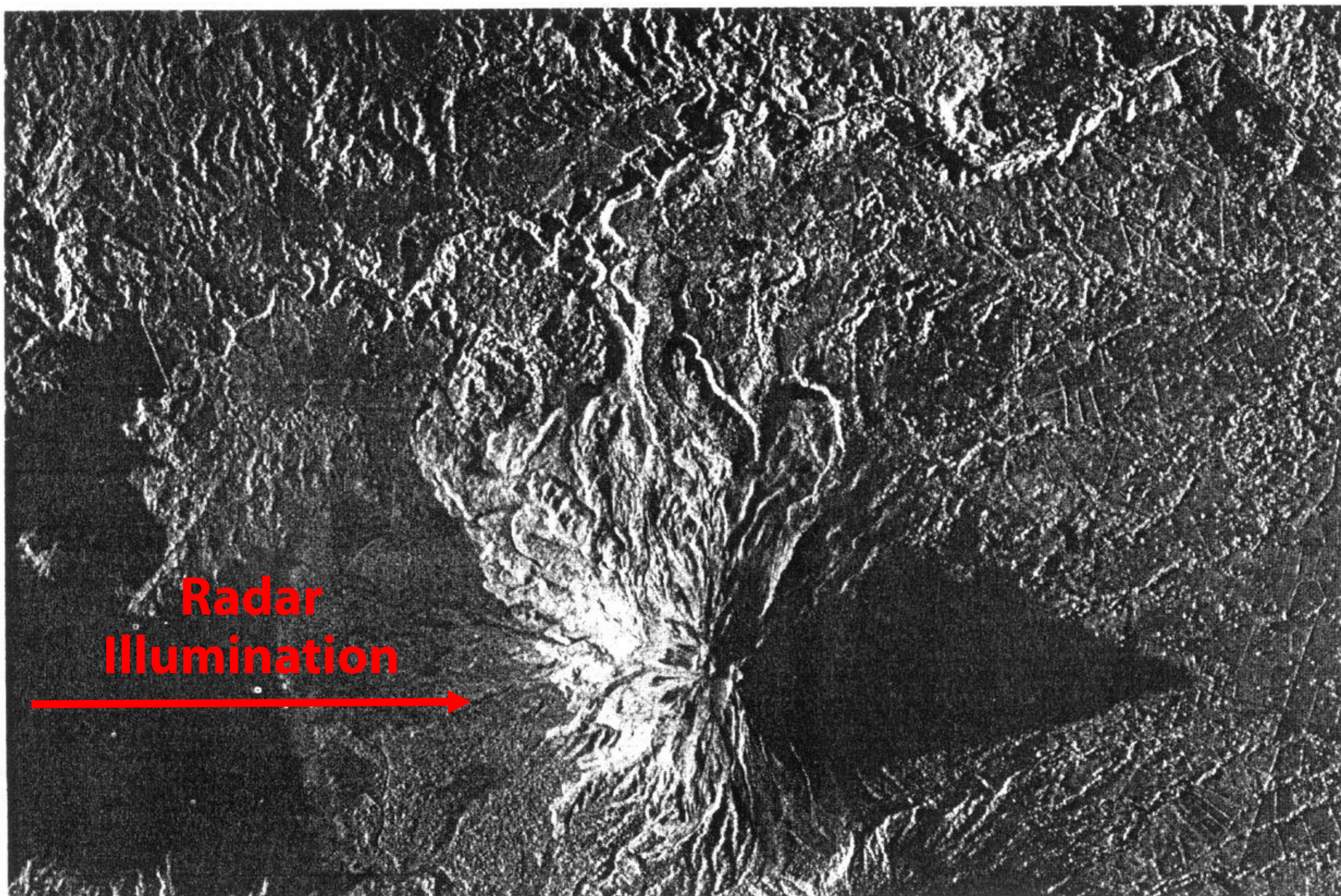
- Since radar is an active technique, it has some strange geometric effects compared to optical images.
- One example is **radar shadow**, where area on the ground behind topographic obstacles is not illuminated at all.



- *Ford et al. (1980)*

Radar Shadows

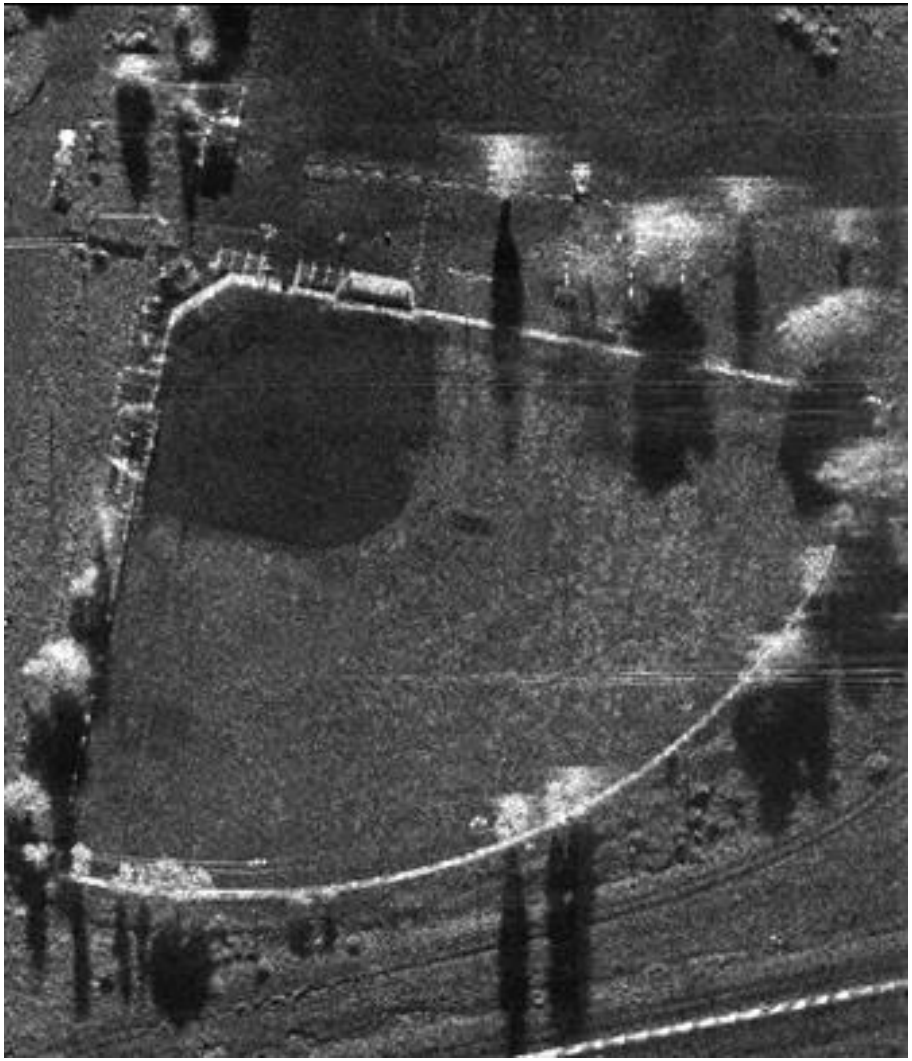
Obvious shadow cast by Mt. Shasta, CA



SAR Imaging

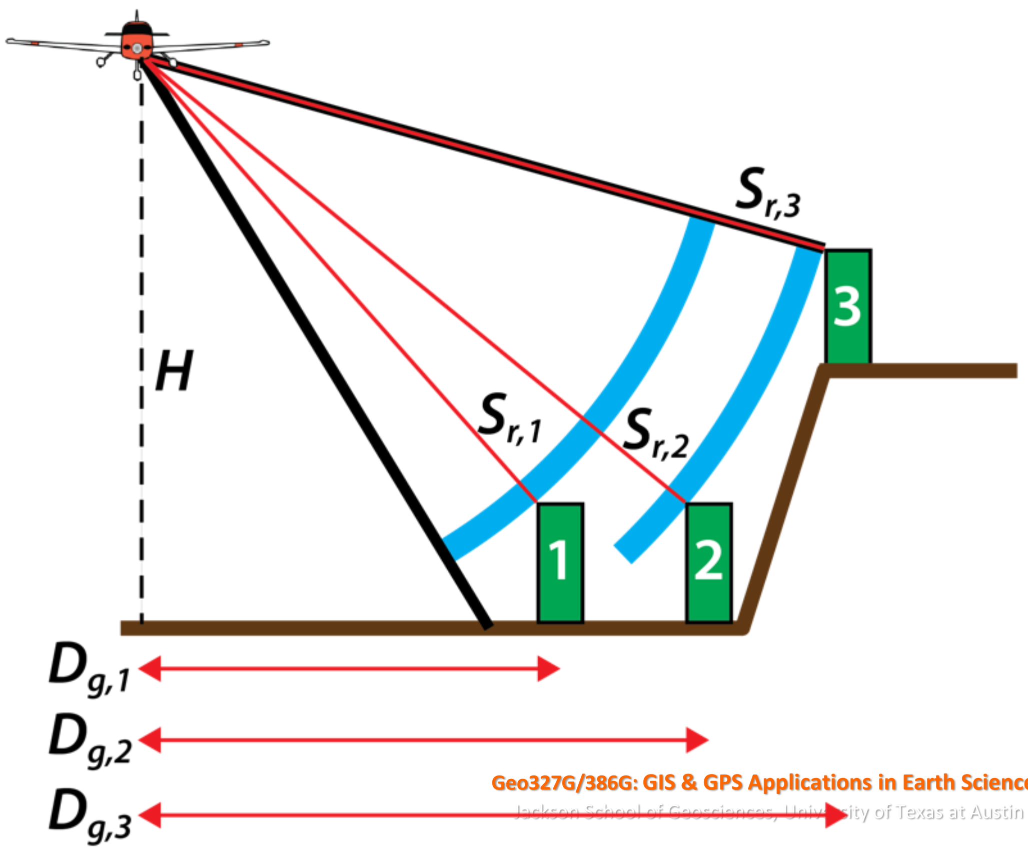
- In practice, *most* modern radar systems use a technique called **synthetic aperture radar (SAR)**.

- Processing technique that uses the Doppler shift of the radar waves to get high resolution images from far away.



SAR + Surface Height vs. Distance

- A problem with radar imaging is that sensor only measures range distance, so we can not differentiate ground distance change from elevation change.



$$S_{r,1} \neq \quad S_{r,2} = S_{r,3}$$

<u>BUT</u>

$$D_{g,1} \neq D_{g,2} \neq D_{g,3}$$

Enter InSAR

- To get around this non-uniqueness, use technique called **interferometric SAR (InSAR)**, which combines data from 2 SAR images.

- Two images can be collected in one pass (i.e., one platform with two SARs) or in two passes (i.e., repeat SAR imaging).

- InSAR can be used to measure topography or surface deformation.

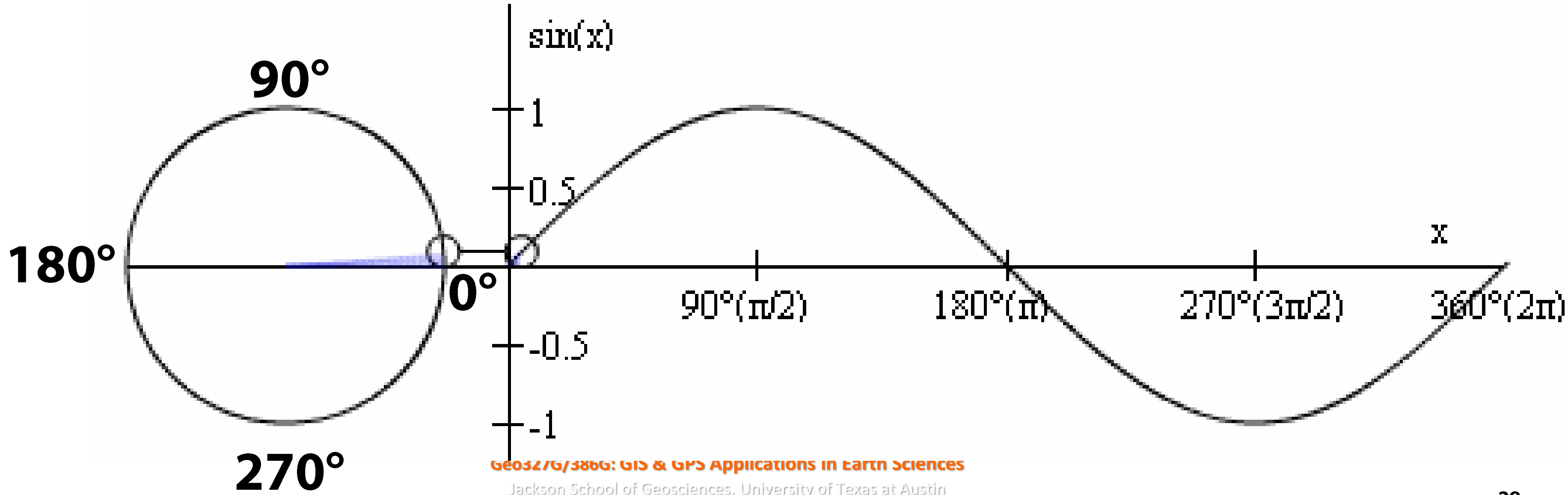
- For both, need to measure **phase** of EM wave.

EM Wave Phase

- The **phase** tells us exactly where in the wave cycle one is. Top of peak? Bottom of trough? Middle?

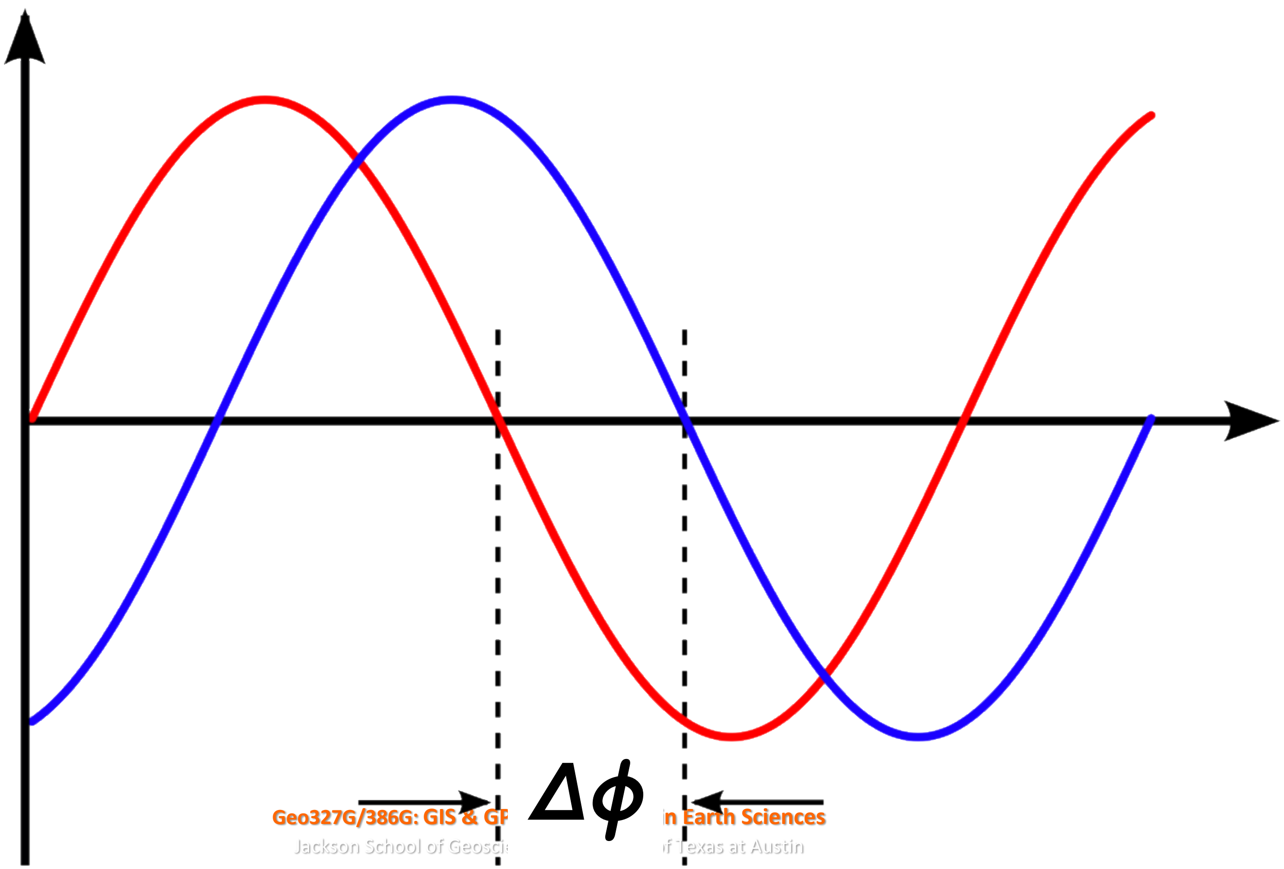
- Measure as **phase angle (ϕ)**, from 0-360°.

Phase Angle



EM Wave Phase Shift

- In particular, we are concerned with the difference in phase between two EM waves, called a **phase shift ($\Delta\phi$)**, which again can range from 0-360°.

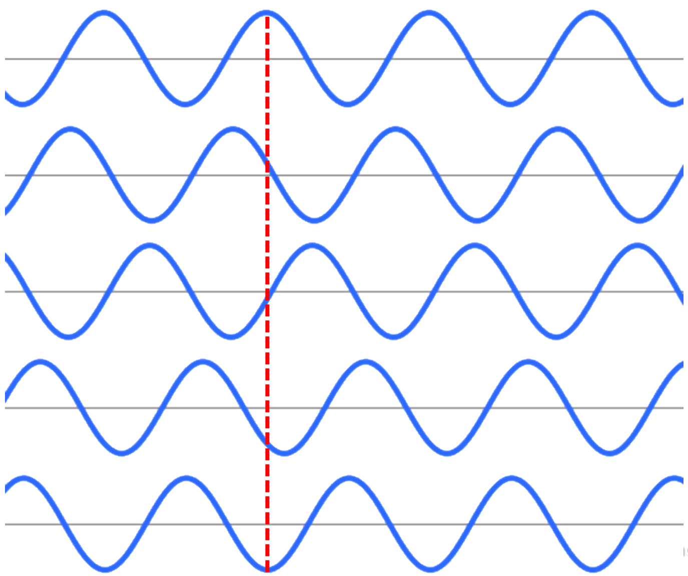


EM Wave Phase Shift

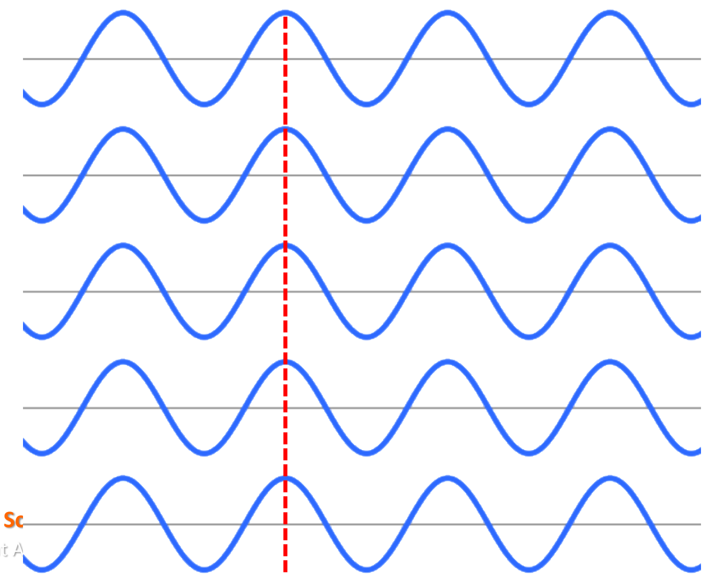
- Most natural radiation has waves of many different phases, called **incoherent radiation**.

- Radar produces radiation waves all at exactly the same phase, called **coherent radiation**.

Incoherent Radiation

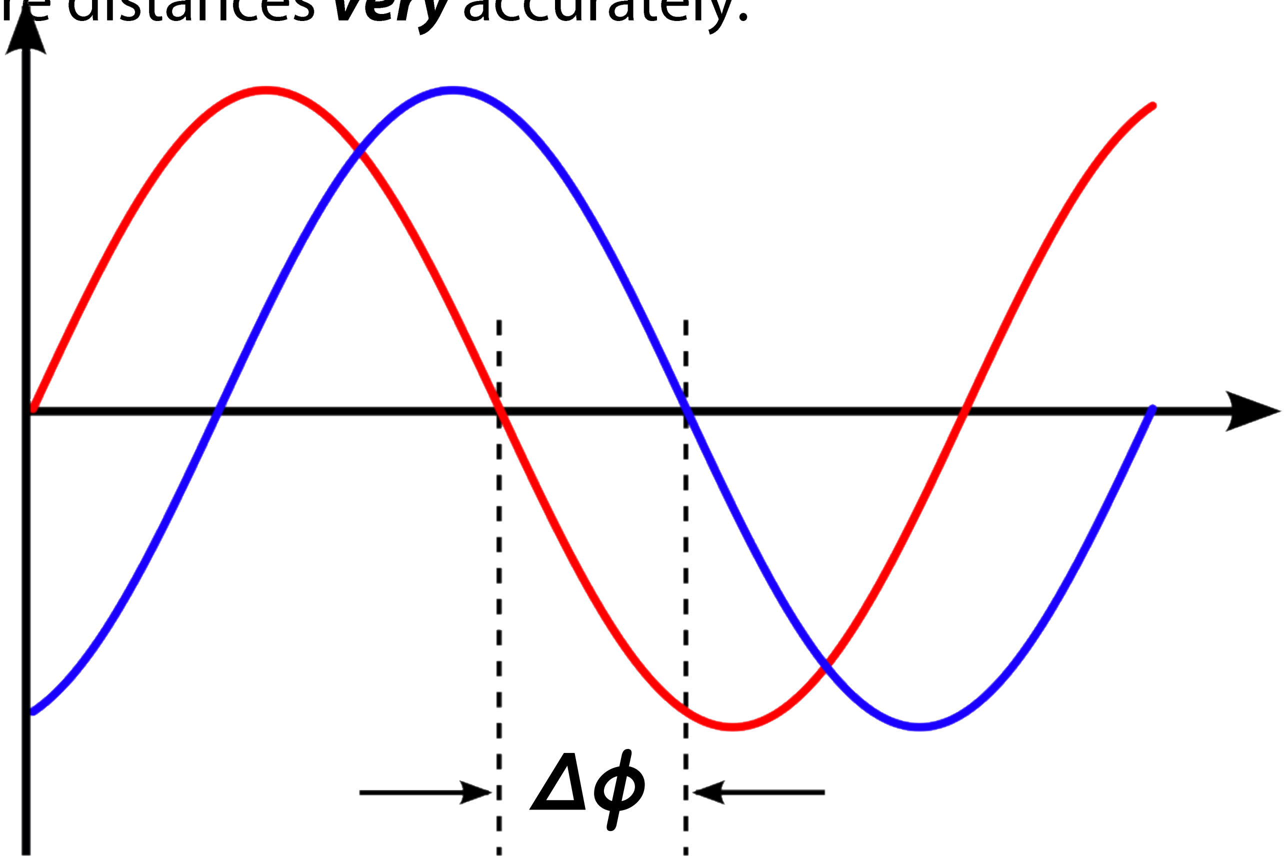


Coherent Radiation



EM Wave Phase Shift

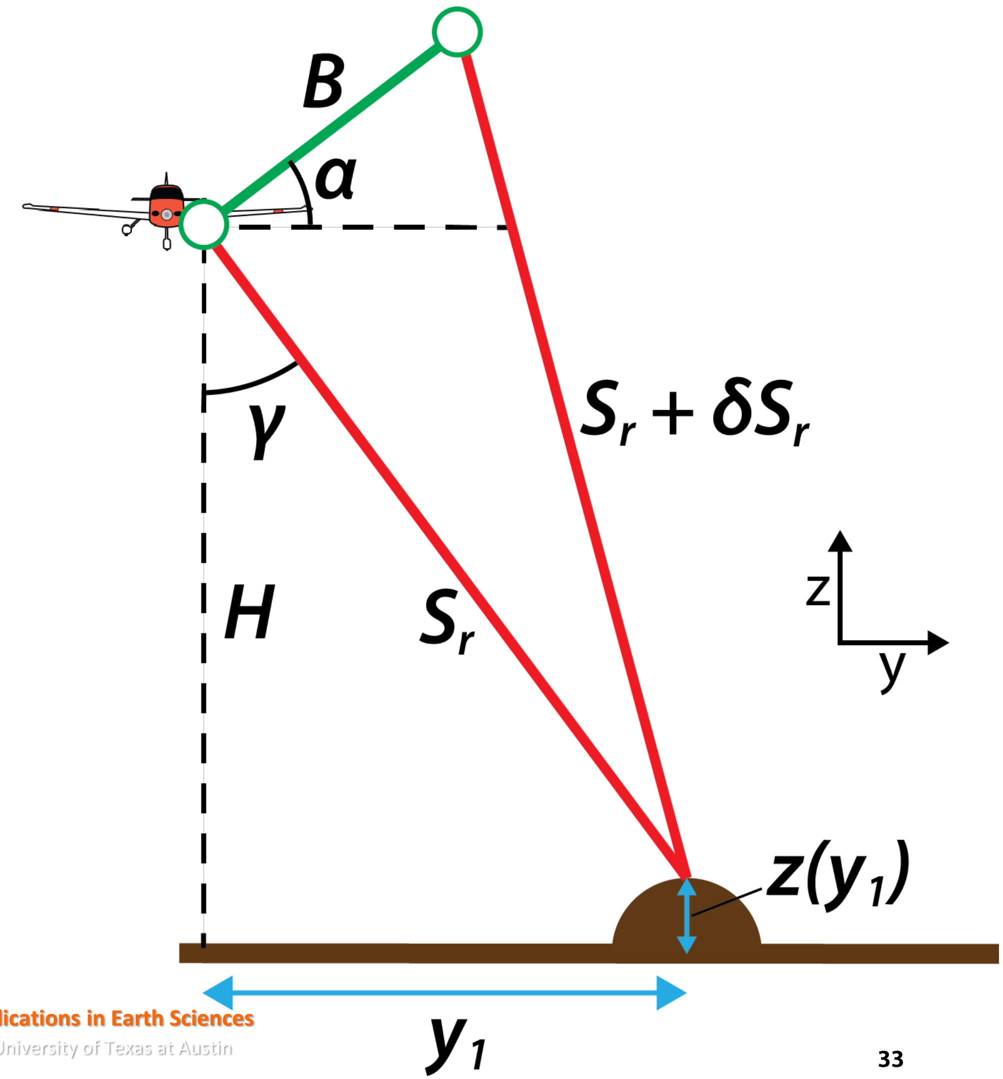
- InSAR takes advantage of ability of radar sensors to measure phase shift between different returned waves. Allows us to measure distances ***very*** accurately.



InSAR for Topography

- Have two radar sensors (or two subsequent passes), separated by a boom (length ***B***, raised above the horizontal by angle ***α***), that both measure returns from one emitted pulse.

- From looking at difference in pulse range (***δS_r***) for same spot, can derive surface topography (***z(y)***)

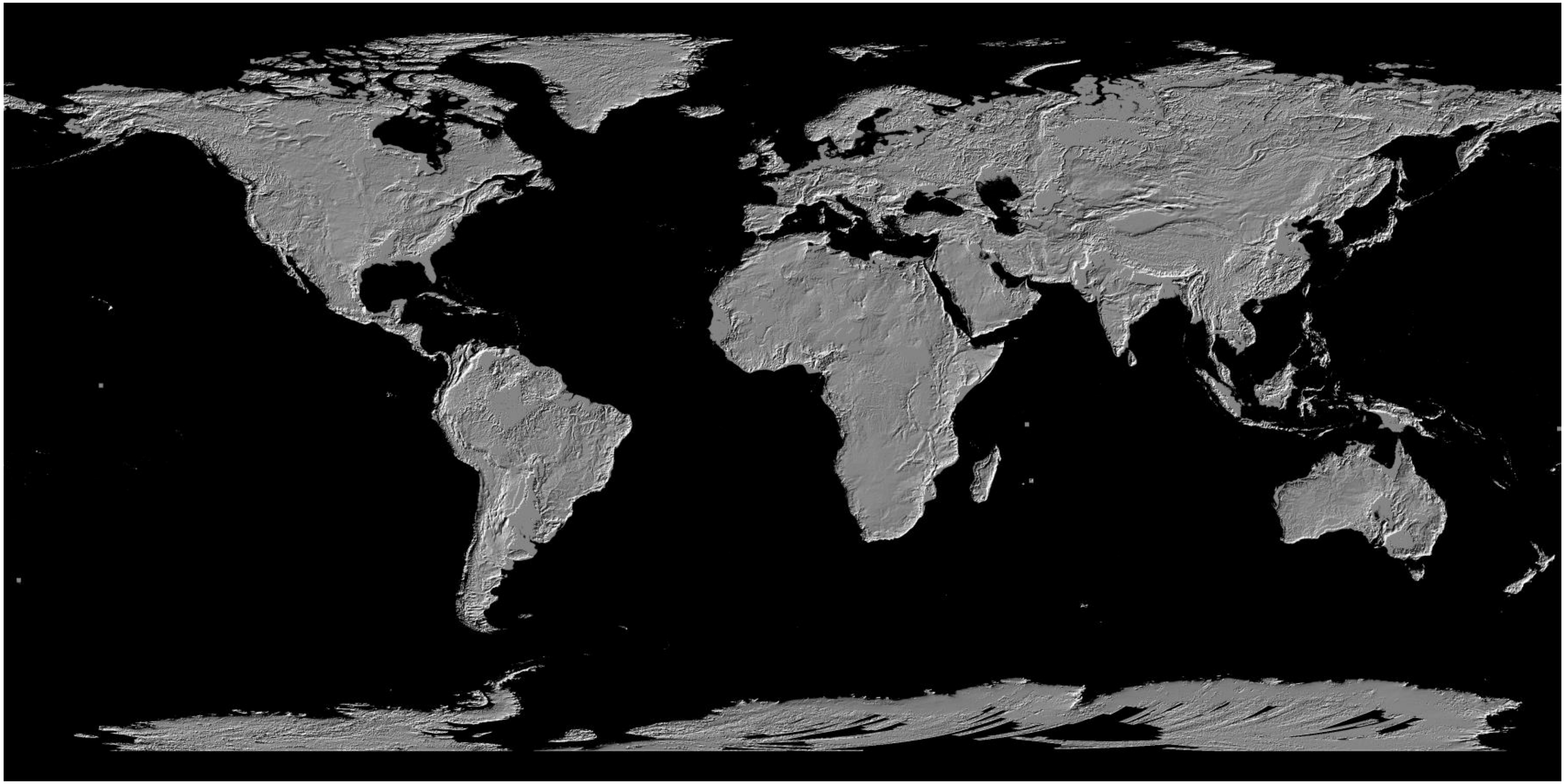


ASTER DEMs

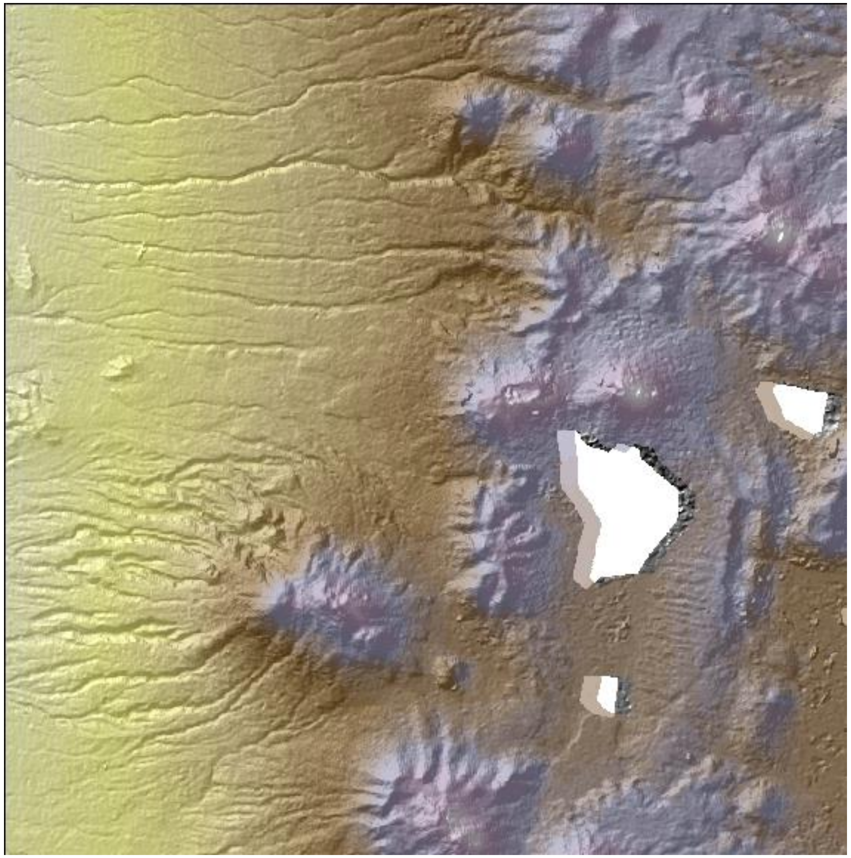
- Advanced Spaceborn Thermal Emission and Reflection Radiometer
- Used for surface temperature, reflectance and elevation
- See ASTER data site for details
- 30 meter–resolution DEMs are available for *registered users* (i.e. GDEM v.3) – global data set!
- If not GDEM then data conversion for individual tiles to ArcInfo is required

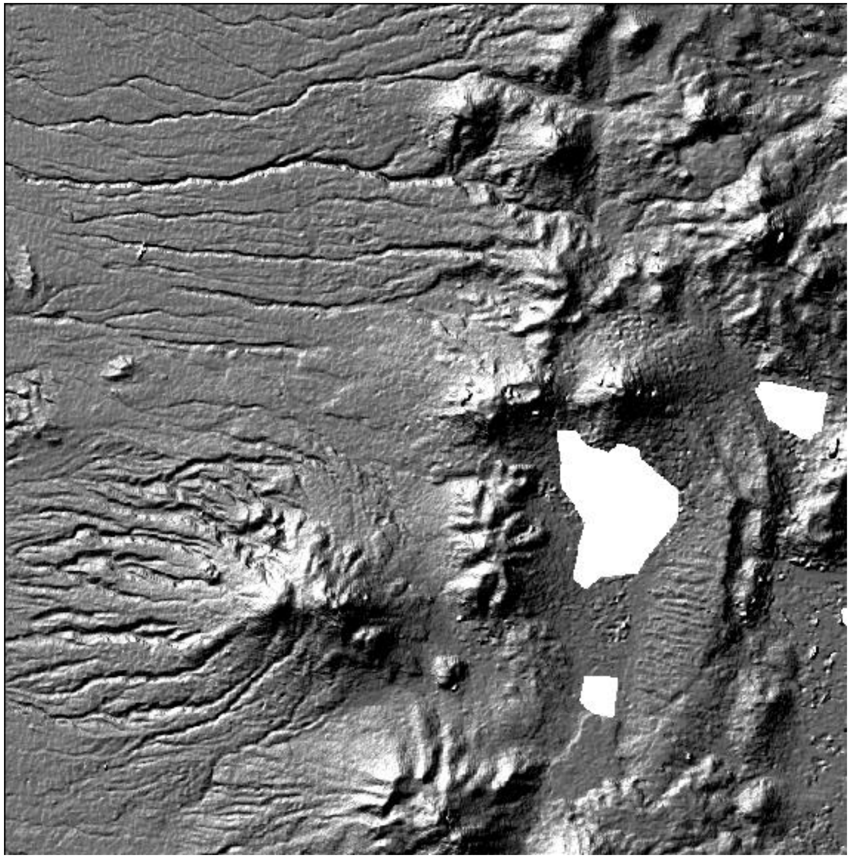
ASTER GDEM

- Global 30 meter postings!



Single ASTER Tile Example

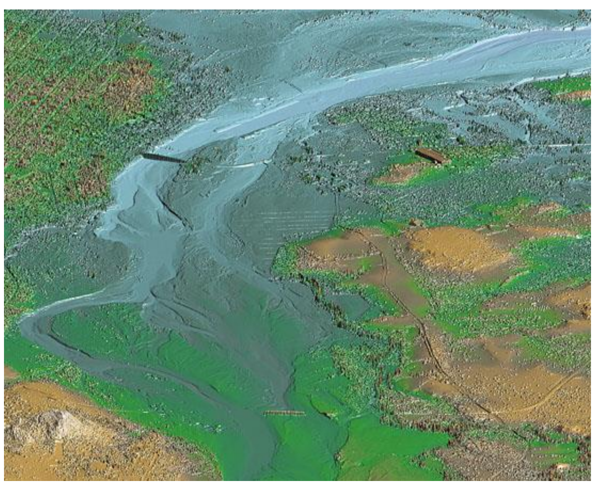




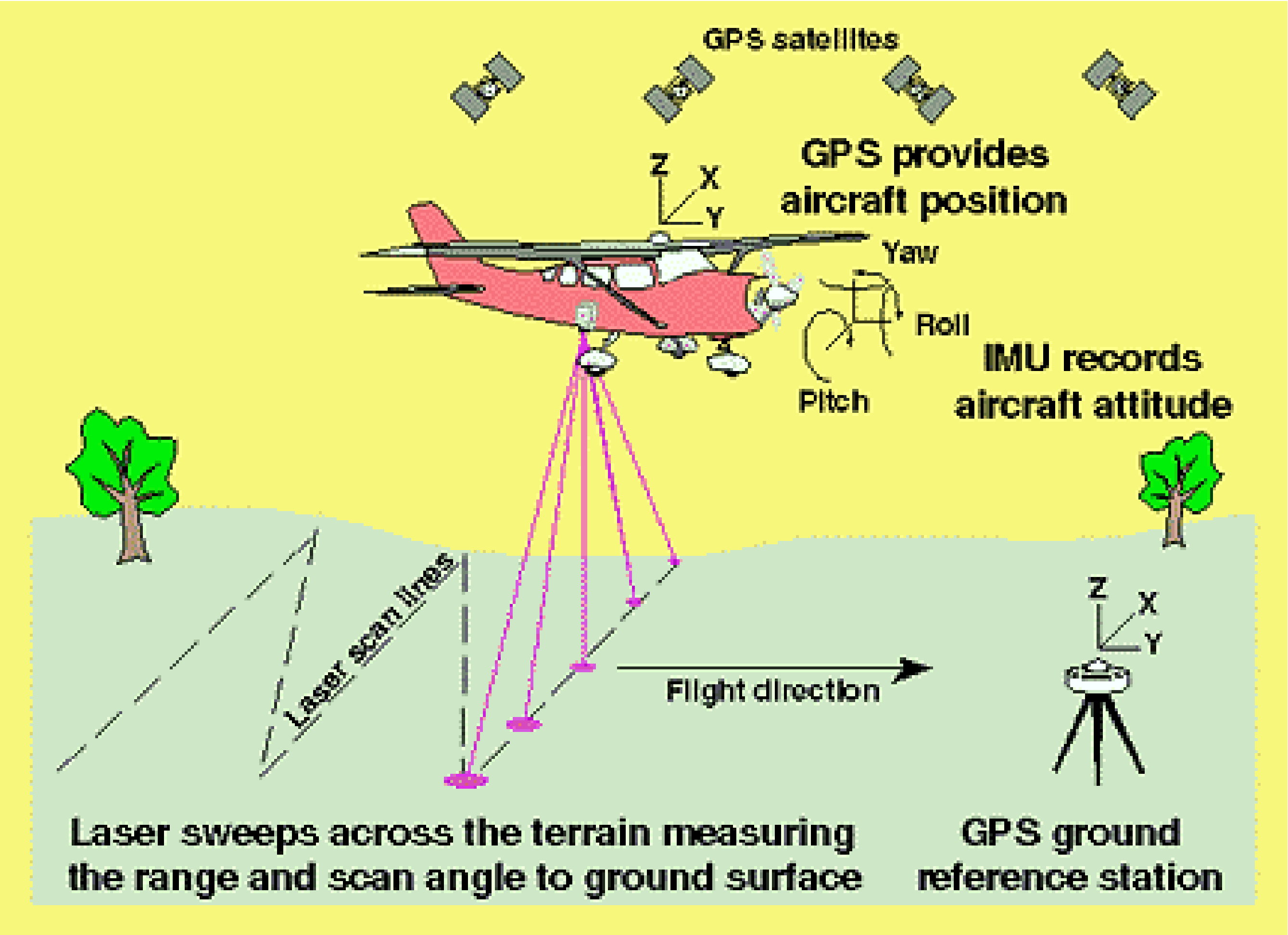
- Lascar volcano, Chile

LIDAR – LIght Detection And Ranging

- = "Laser Radar": two-way ranging technique using a laser scanner
  - Airborne LIDAR
  - "Scanning" (Ground-based) LIDAR



Airborne LIDAR



From Gibeaut, 2004

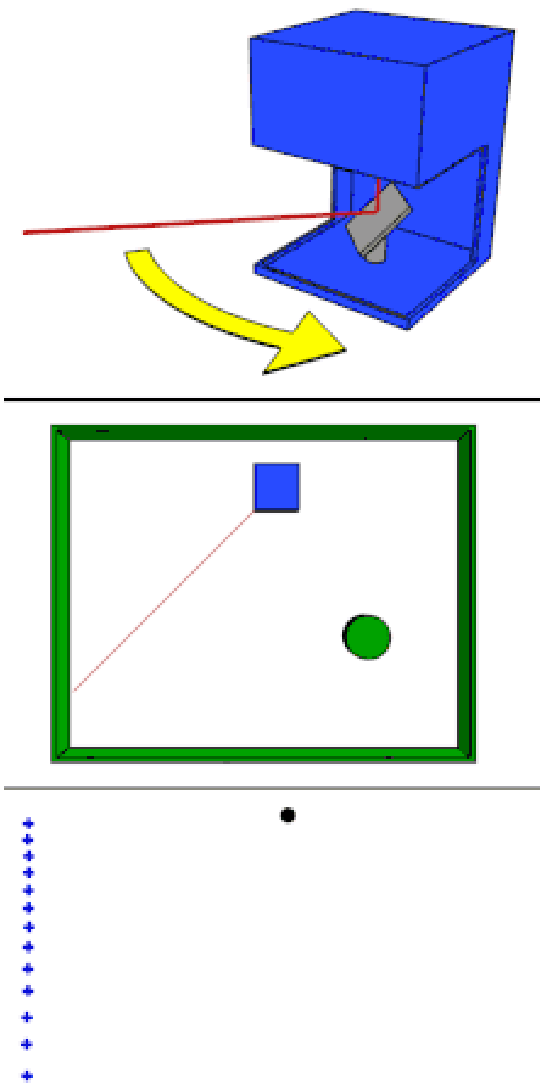
Airborne LIDAR

- Requires
  - Precise positioning for aircraft (DGPS ground and air)
  - Laser ranges & scan angles
  - Platform position (yaw, pitch, roll of aircraft)
- Produces
  - Swaths 100's meters wide
  - Accuracy of 1-4 cm in x,y,z

BEG's (old) LIDAR unit in a Cesna 206

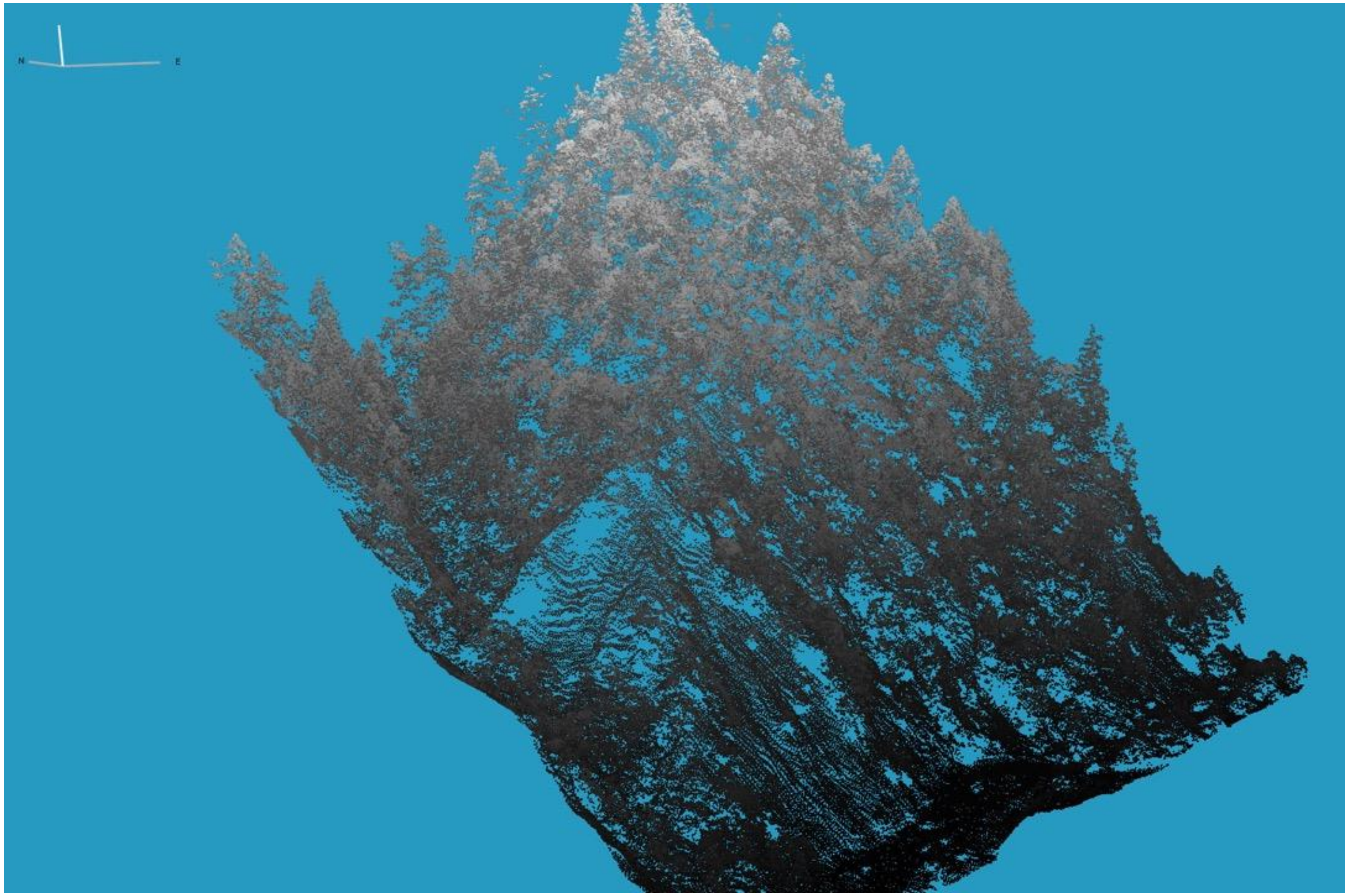
Lidar Scanners

- Lidar instruments have rapidly rotating mirrors (**scanners**) that point the laser pulse in different directions.
- This builds up a series of return pulses.
- Typical sampling rates are of the order of 100k pulses per second.

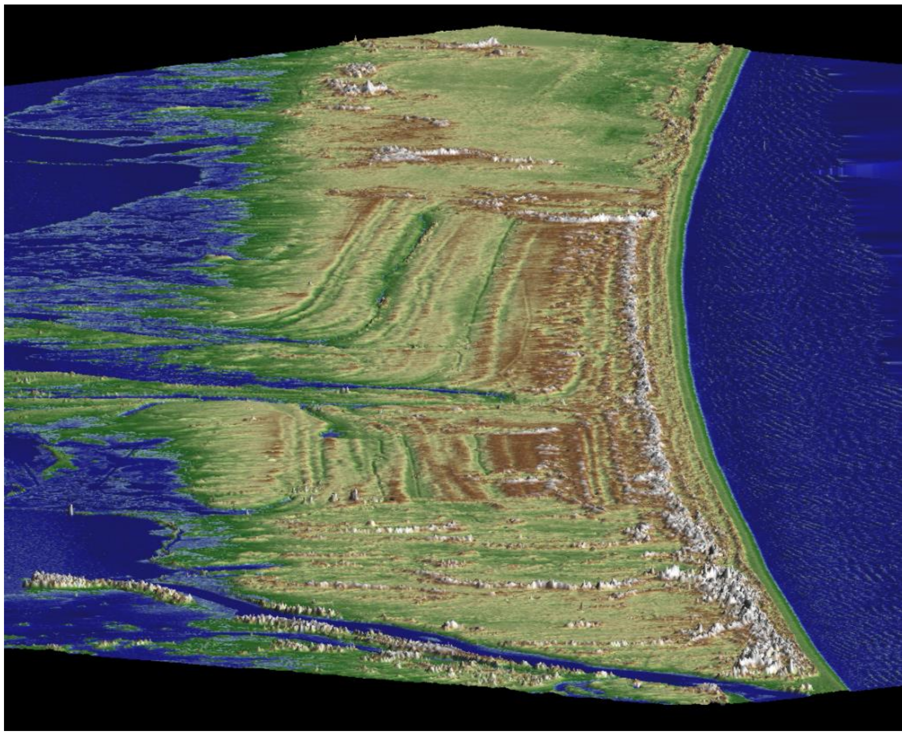


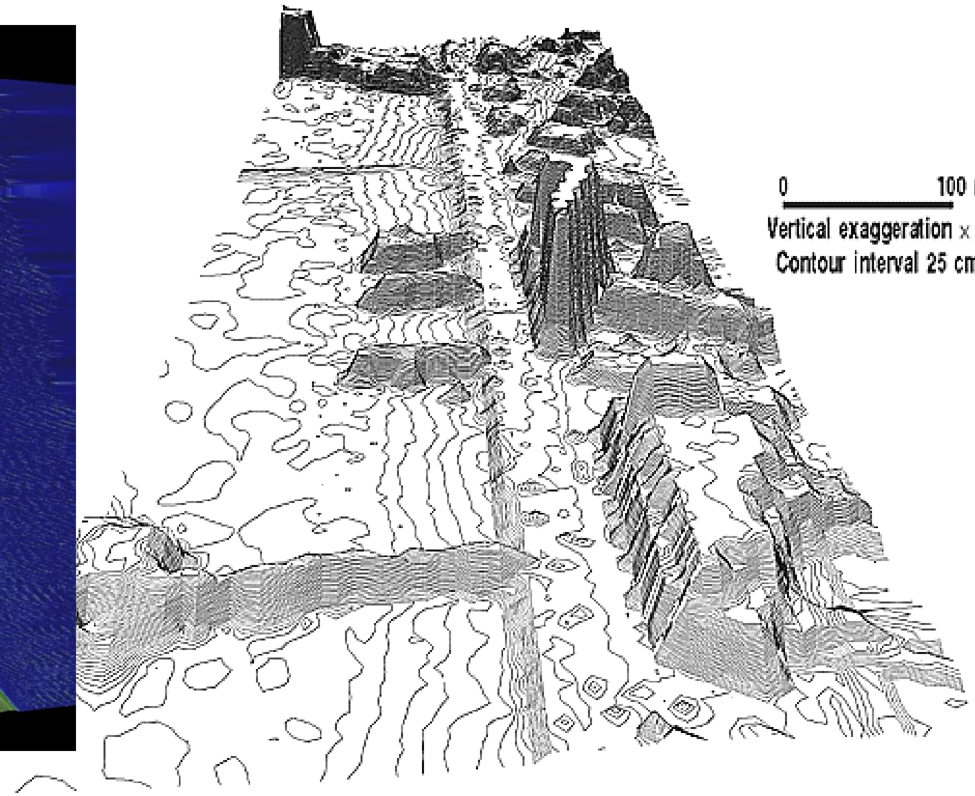
Point Clouds

- A point cloud is a set of points in space, each with precise X/Y/Z locations. This is what a lidar scanner measures, and is **true 3D data**.



Matagorda Island LIDAR



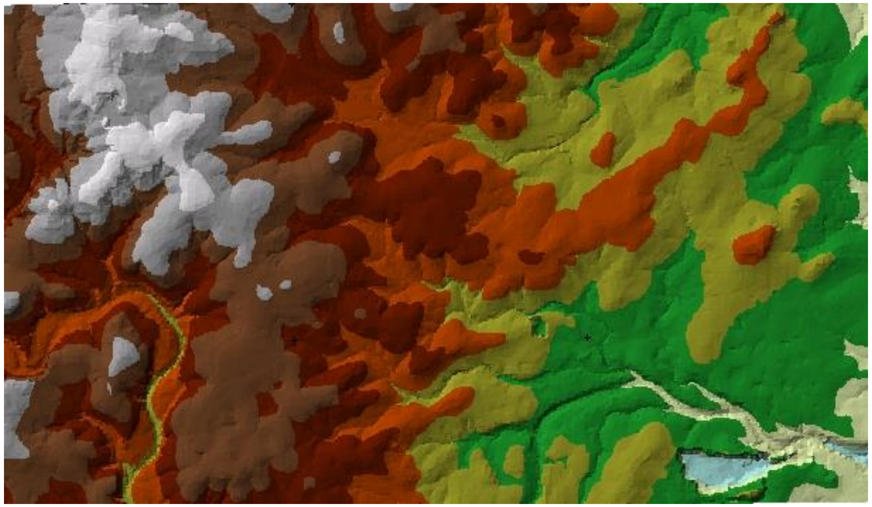


Contour interval = 25 cm!

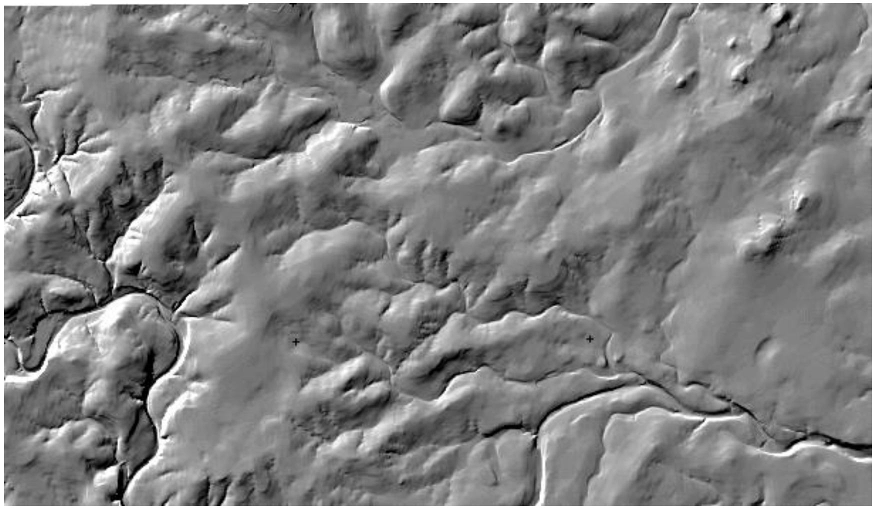
From Gibeaut, 2004

Airborne LIDAR in ArcGIS

1. Convert LAS file(s) to "Multipoint" feature class
2. Use Multipoint to create a TIN "Terrain"
3. Covert TIN to DEM (DTM)



Terrain Model (TIN)



hillshade of DEM (raster)

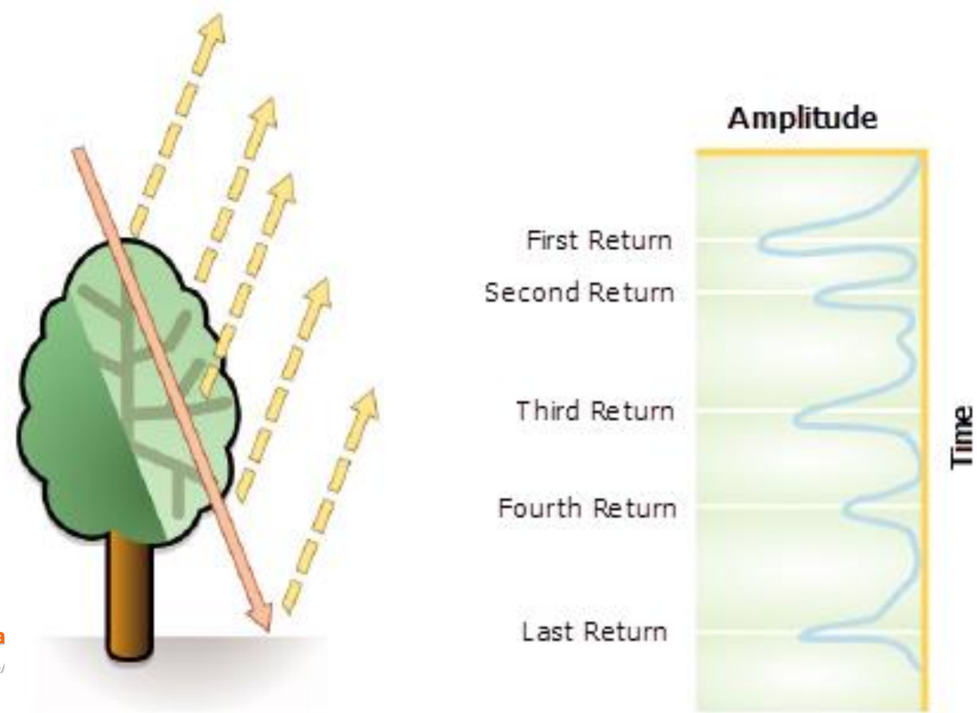
Data from TNRIS

Lidar Multiple Returns

- A ***major*** advantage of lidar is that the emitted power is sufficiently strong that it can often go ‘through’ vegetation (*gaps between leaves*).

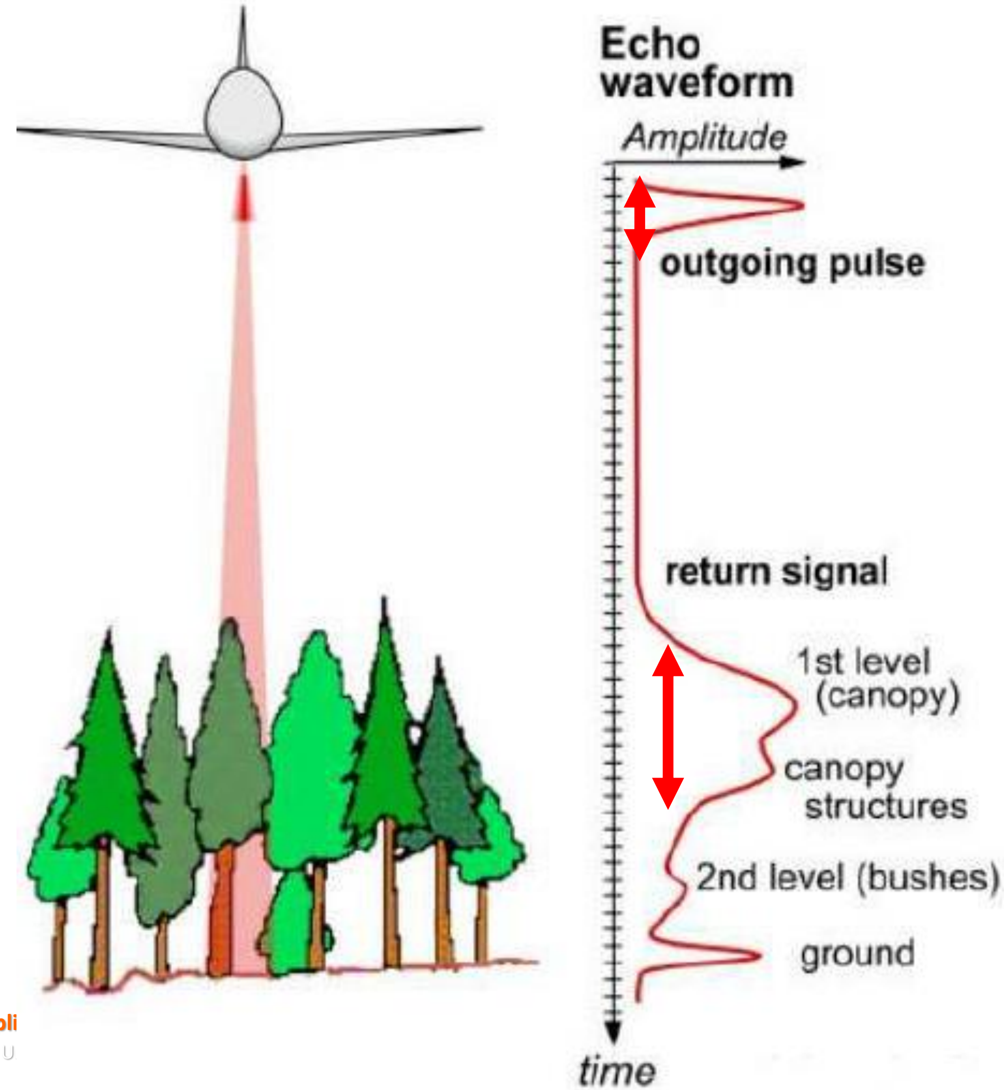
- Laser will bounce back (and give a return) every time it encounters something,
  e.g., a tree branch.

- This is referred to as a **multiple return signal**.



Lidar Multiple Returns

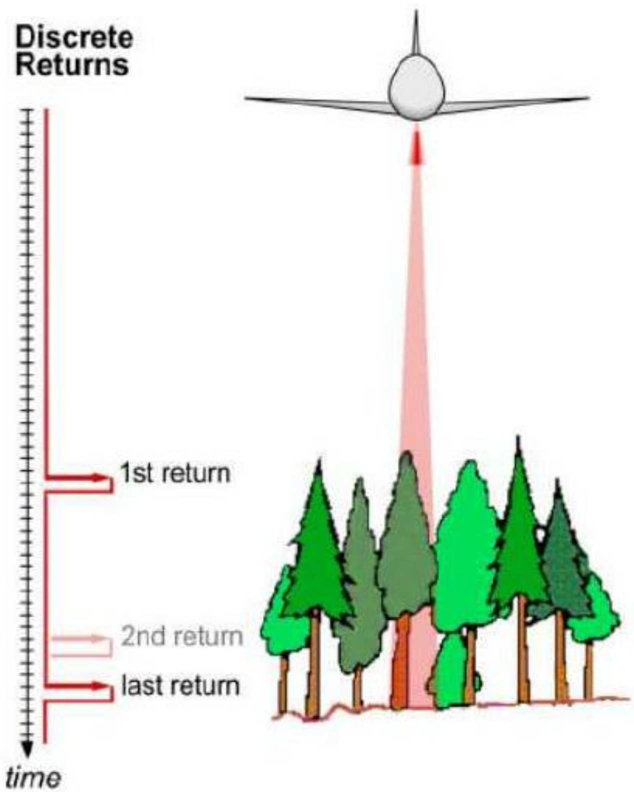
- Recording complete character of all returns, called measuring a **full waveform return**. This requires a very sensitive sensor ($$).
- Structure of returned pulse tells us how rough the surface is within the beam area.

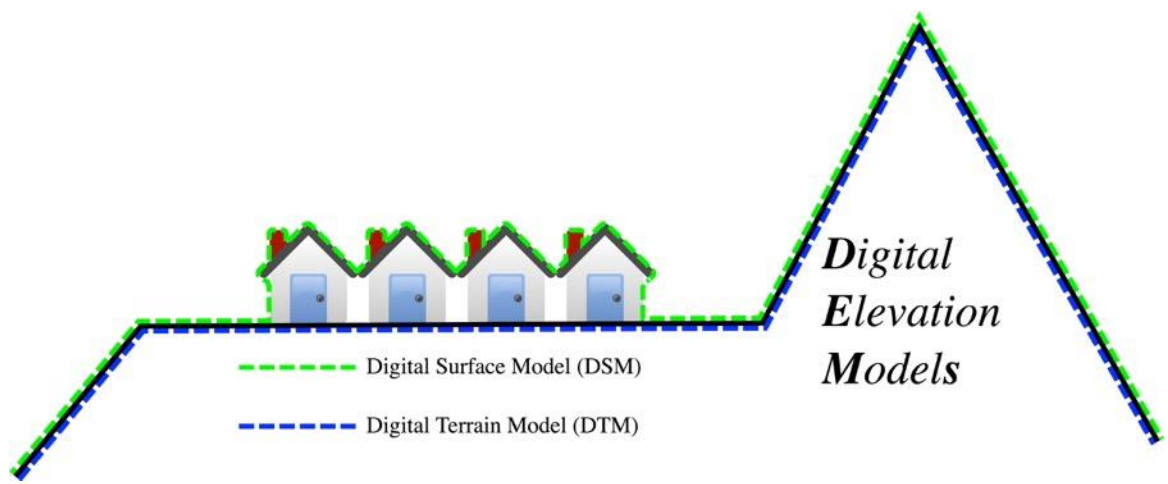


Bare Earth Filtering

- Looking only at the last return to calculate a DTM is often called **bare Earth filtering**.

- *Also many other lidar point-classification schemes out there to filter out buildings, power lines, etc. etc.*



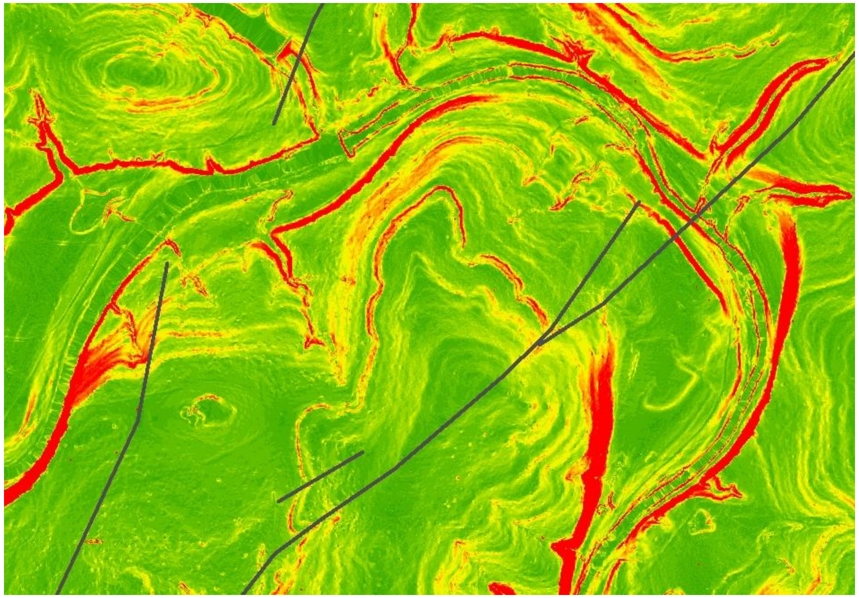


Lidar Pros and Cons

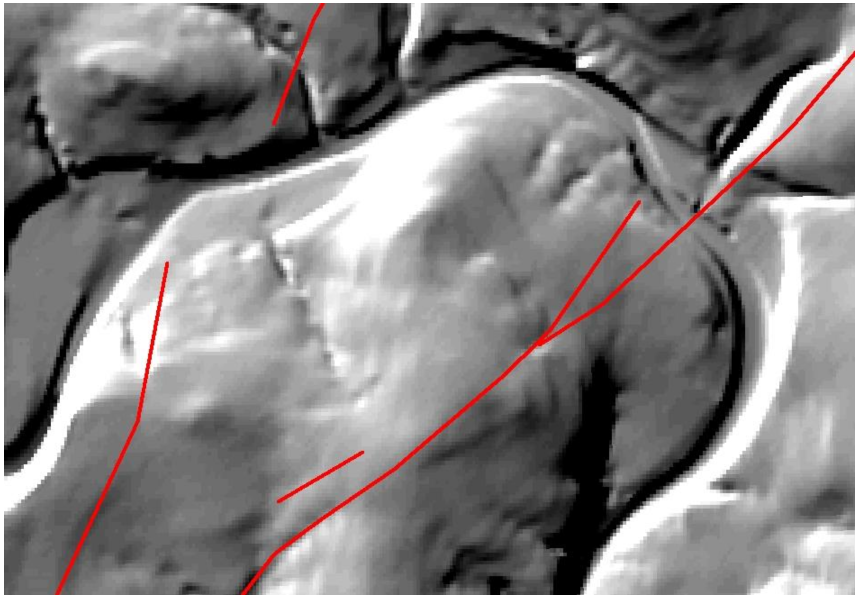
- Lidar is an incredible tool and has (*IMHO*) mostly pros:
  - Get multiple returns, so can create DTM + DSM; can also study tree canopy structure using full waveform data.
  - Very high resolution topography (meter/pixel).
  - High vertical (<5-10 cm) precision; critical for change detection.
- Some cons exist also:
  - Can be very expensive (several hundred $\$/km^2$).

Application: Airborne LIDAR slope mapping

- Mapping of geologic units and faults by changes in slope, e.g. central Texas hill country



Slope Map

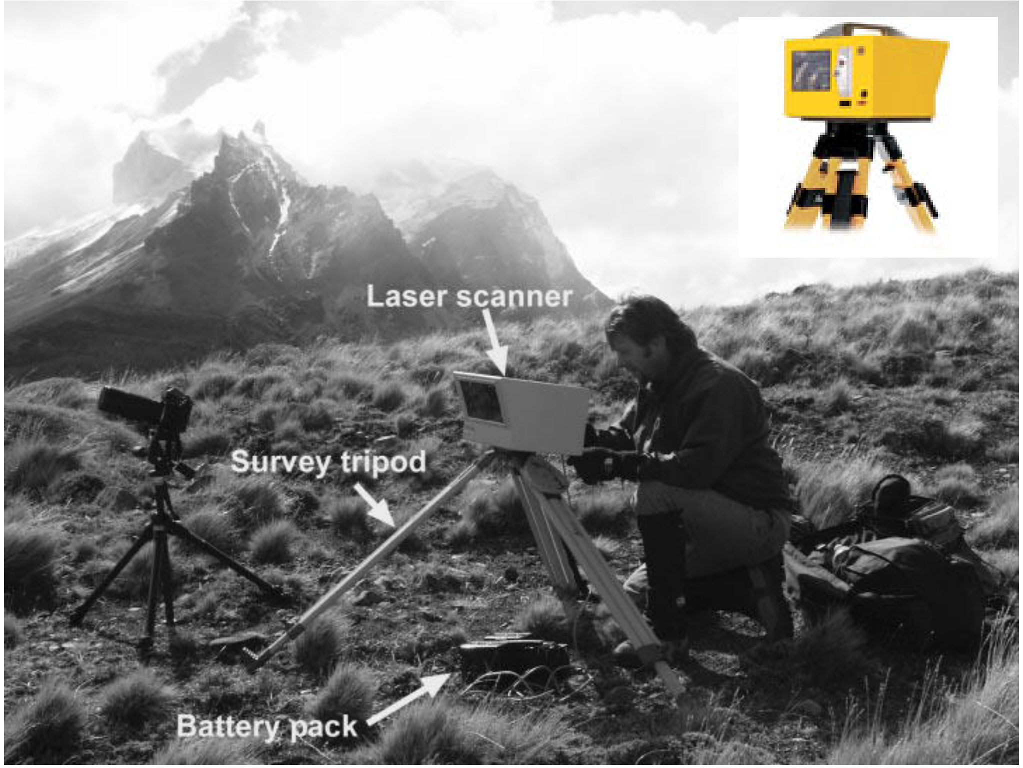


hillshade of DEM (raster)

Cretaceous Glen Rose and Walnut Formations (carbonate rocks)

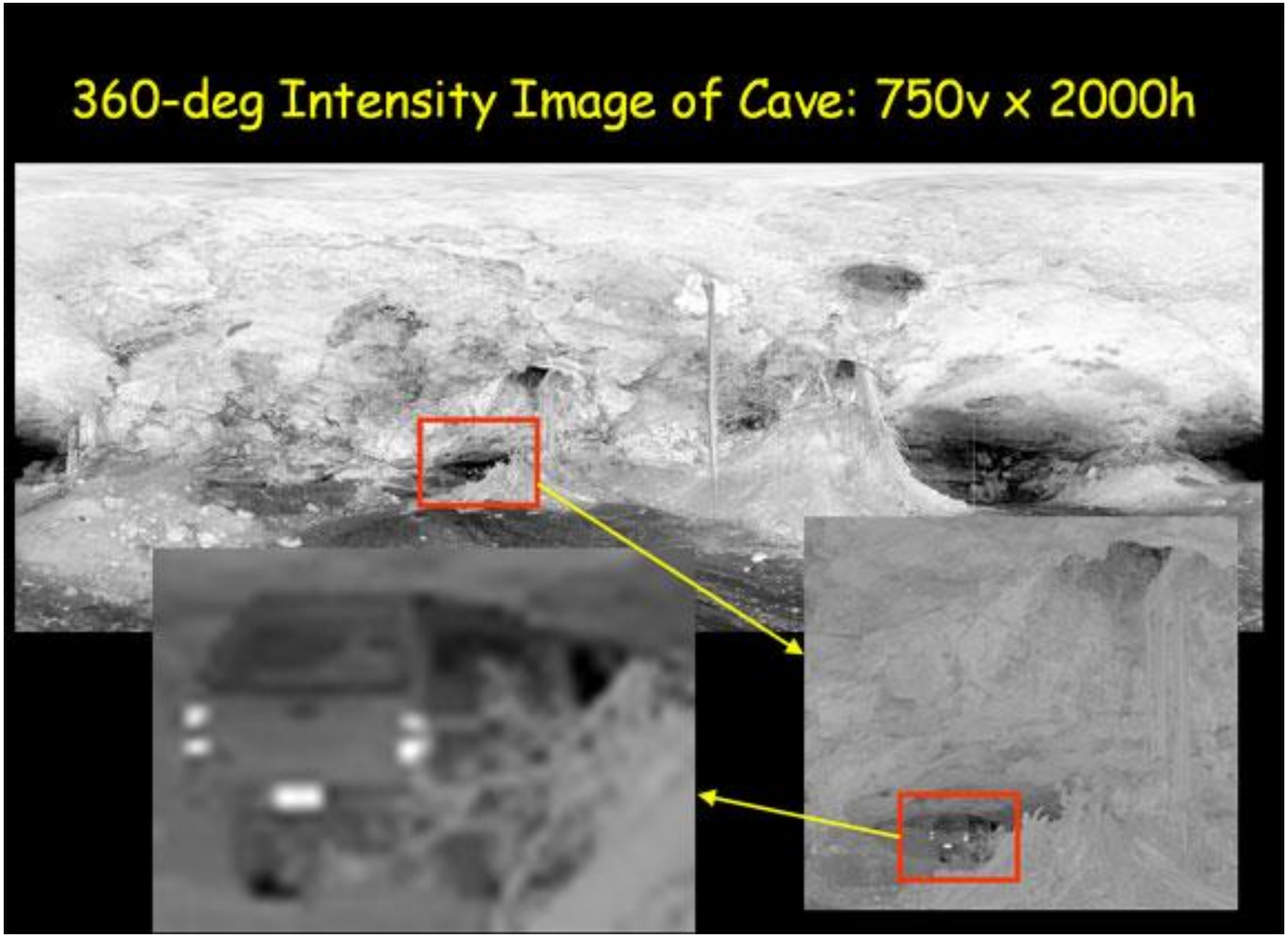
Terrestrial LIDAR

- Rapid, quantitative characterization of outcrops
- 2,000 pts/sec, 10-15 mins/scan
- "Point clouds" rendered with software



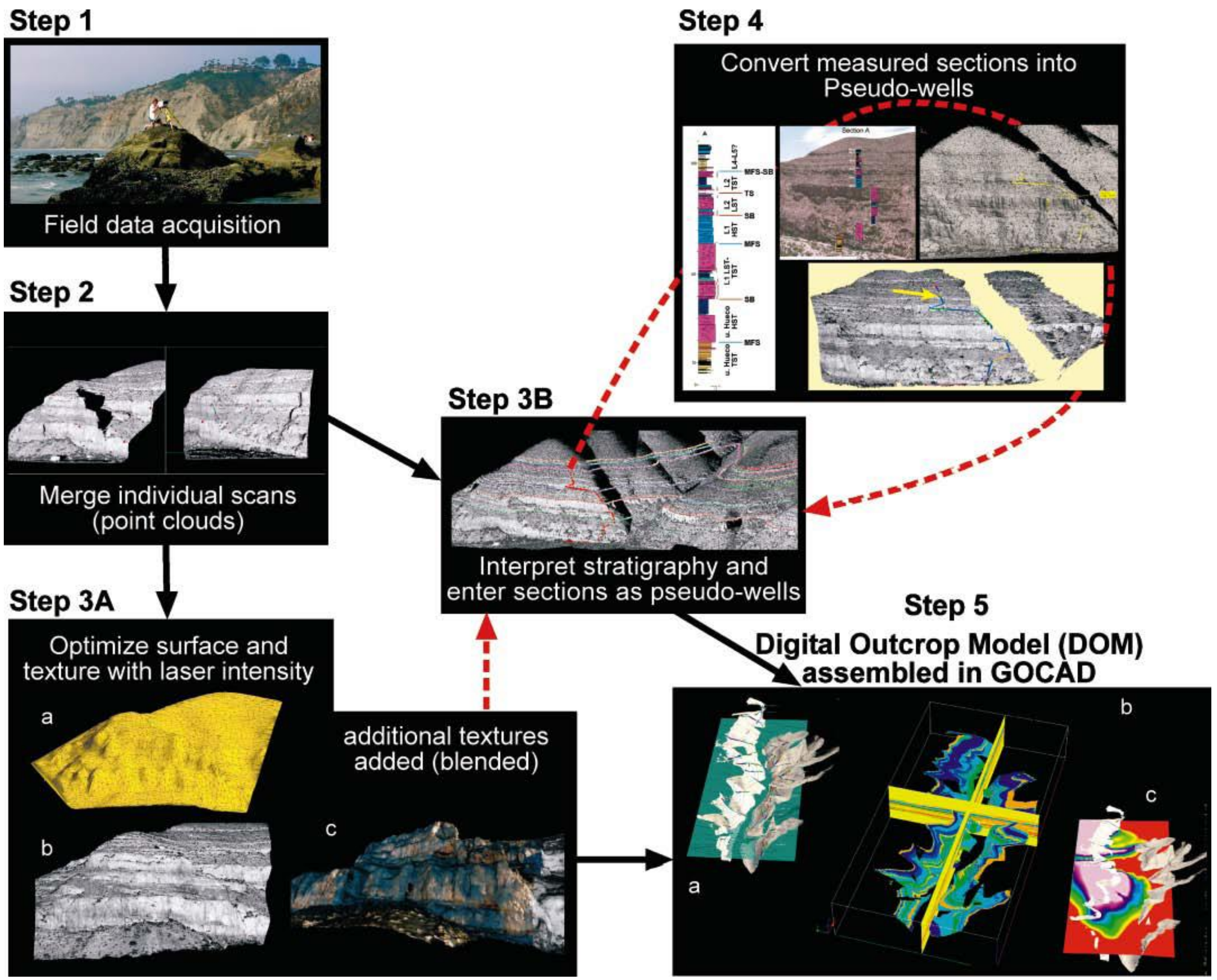
From Belian et al., 2005

360º Cave Image



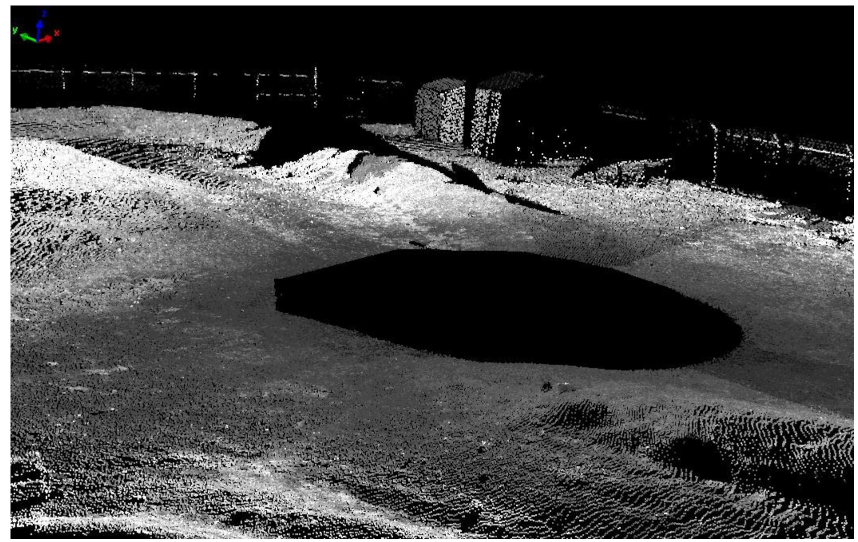
From Gary

Terrestrial LIDAR Applications



From Belian et al., 2005

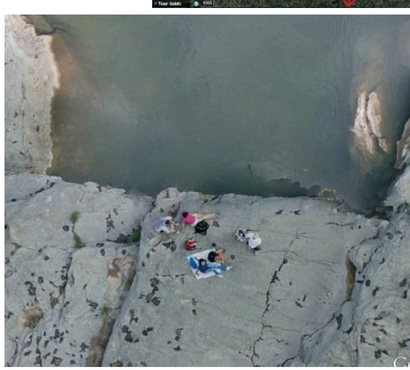
Scanning Lidar on robotic rover



Photogrammetry: “Structure from Motion: SfM”

- Unmanned Aerial Vehicles (UAVs) and photogrammetry software

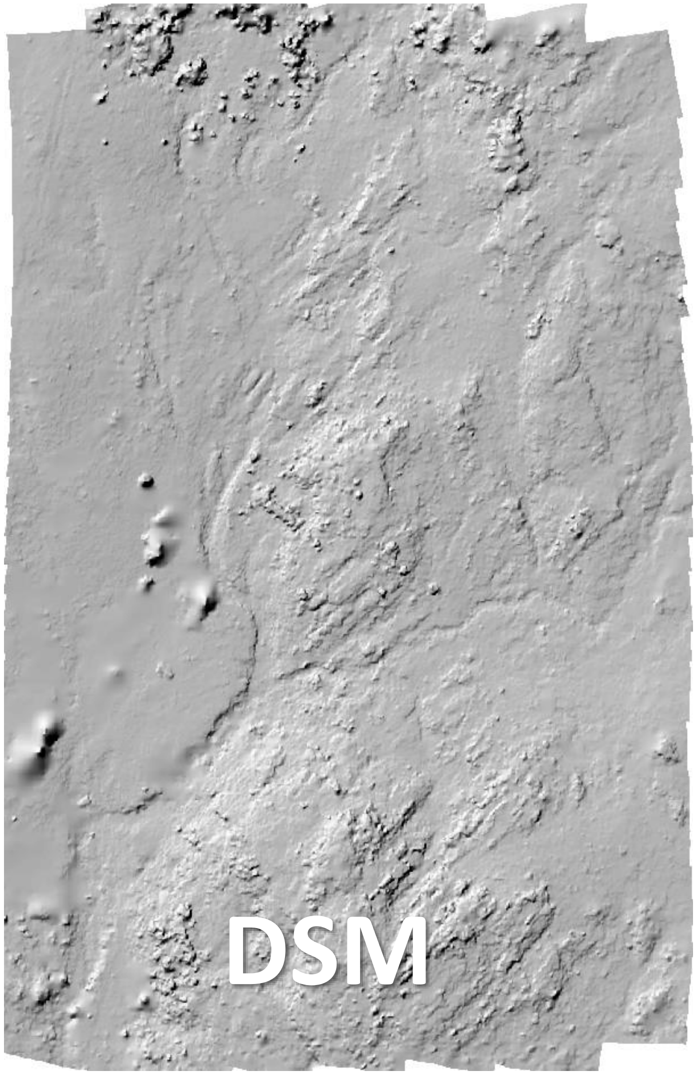
274 stitched UAV images



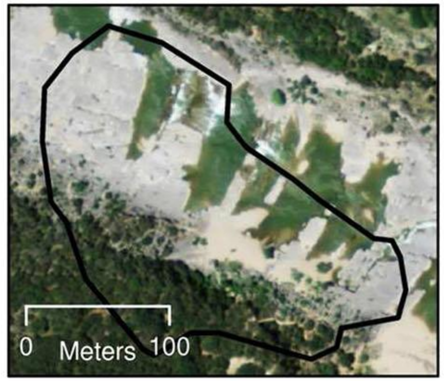
1.5 cm resolution!

Google Earth image

Mason Mountain SfM and Lidar DTM



Custom Photogrammetry



SfM = “Structure from Motion” photogrammetry

From Fonstad et al., 2013