Carleton
UNIVERSITY

GEOM 3002 - Lecture 4

Interpretation and Thematic Mapping of Land Use and Land Cover
&
Image Geometry, Flight Planning, Photogrammetry

Readings

Aspects of **Land Use / Land Cover Mapping** are included in:

- Lillesand et al. 2015: Chapters 8.1, 8.2, 8.9
- Jensen 2015 (Intro to Image Processing): LULC classification schemes, pp. 364-376.
- Jensen 2007, RS of the Environment: An Earth Resource Perspective has many sections on classification of different land cover types (vegetation, water, urban, soils, etc.). pp. 450-456 have specific details on what was presented in the lecture.

Aspects of **Camera Geometry, Flight Planning and Photogrammetry** are included in:

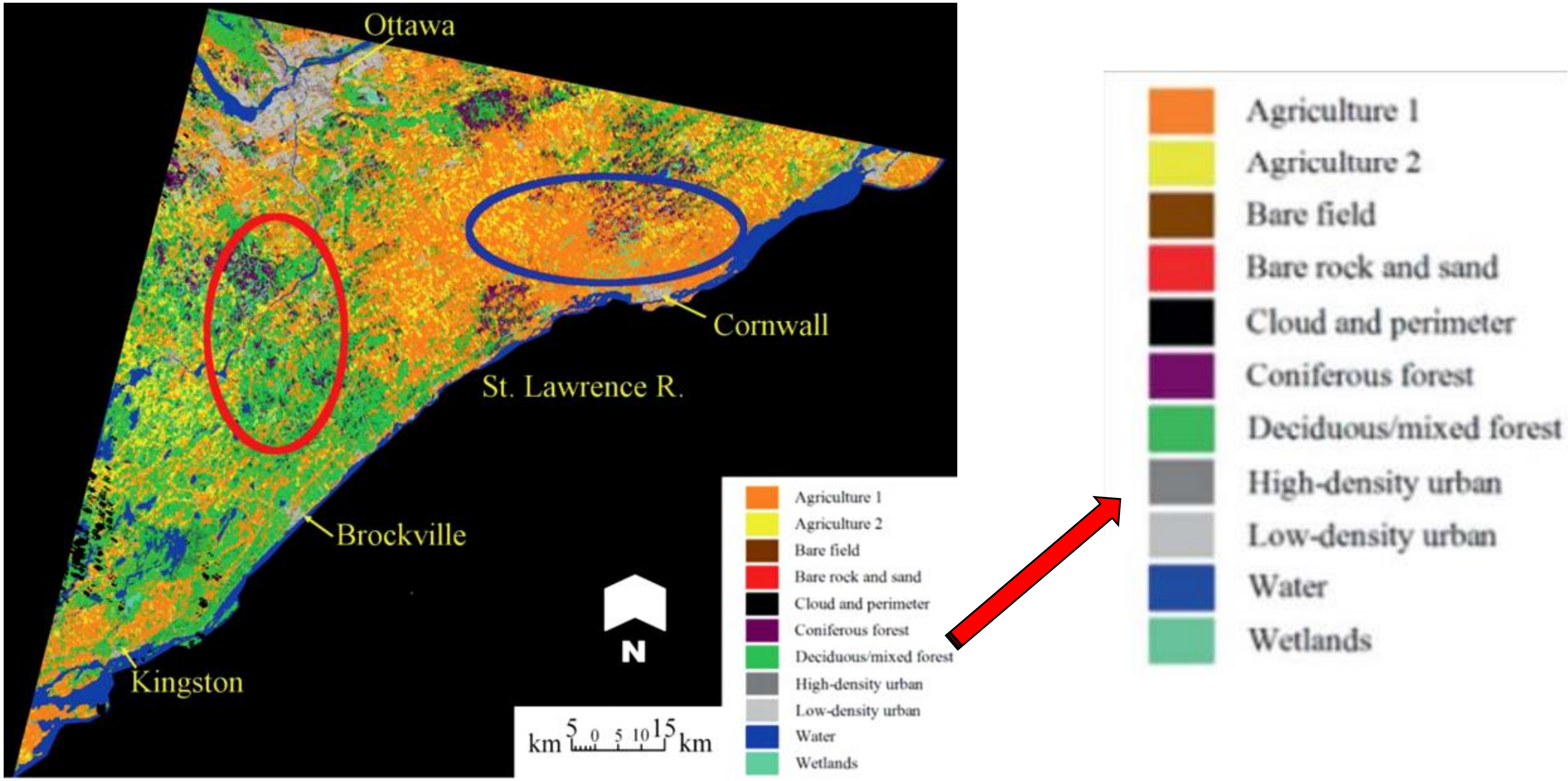
- Lillesand et al. 2015: Chapters 3.1-3.7 (up to page 187); Chapter 3.11
- Jensen 2007, RS of the Environment: An Earth Resource Perspective: pp. 137-161.

Thematic Mapping of Land Use and Land Cover

Land Use/ Land Cover (LULC) Mapping

- Mapping land use / land cover since 1940s
- Maps at all scales (local – national – global)
- Land cover – features present on the surface
  - E.g. lakes, concrete, maple trees, corn, etc.
- Land use – relates to human activity or economic function
  - E.g. residential use, agricultural use, business district, etc.

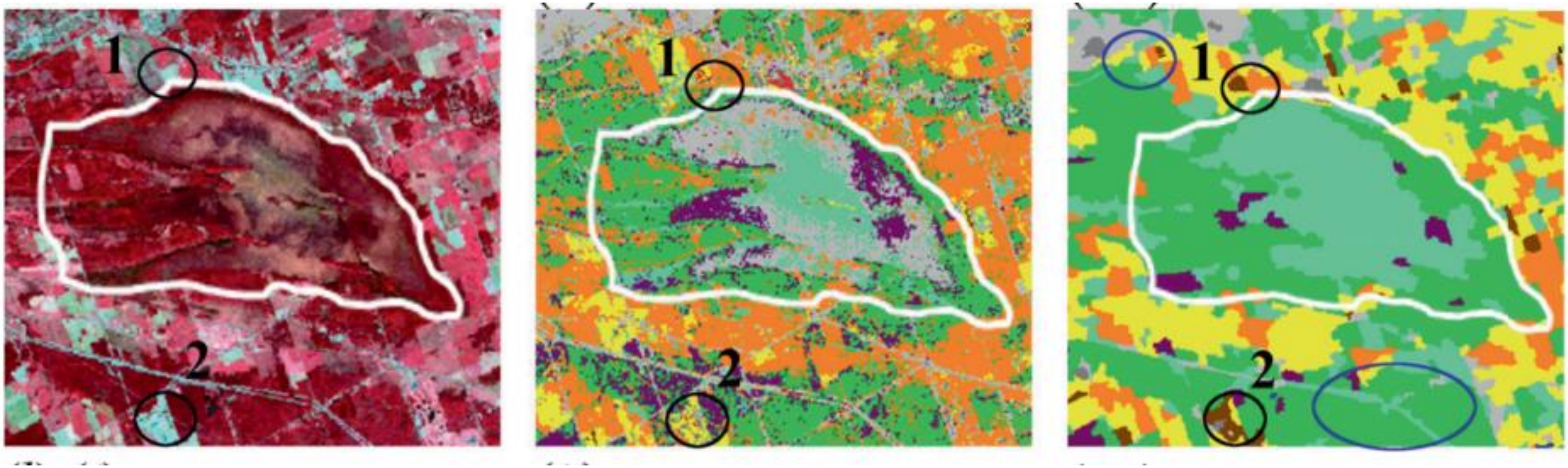
Examples of LULC Maps



Maximum Likelihood Classification of LULC using Landsat image, Eastern Ontario

Dingle Robertson & King, 2011

Examples of LULC Maps



Dingle Robertson & King, 2011

Common LULC Classification System Attributes

- Hierarchical
  - Broad classes are composed of ≥ 1 subclass
    - E.g., single-family residential, multiple-family residential ⟺ residential
  - Can change class detail with change in imagery scale
- Mutually exclusive
  - No overlap (or fuzziness) of any classes
    - E.g., deciduous forest and evergreen forest are distinct classes.
- Exhaustive
  - Classification system should be applicable over extensive areas
  - All land-cover classes present in the landscape are accounted for
  - Or sometimes only certain classes are required and the rest of the map area is masked out
    - E.g., water bodies

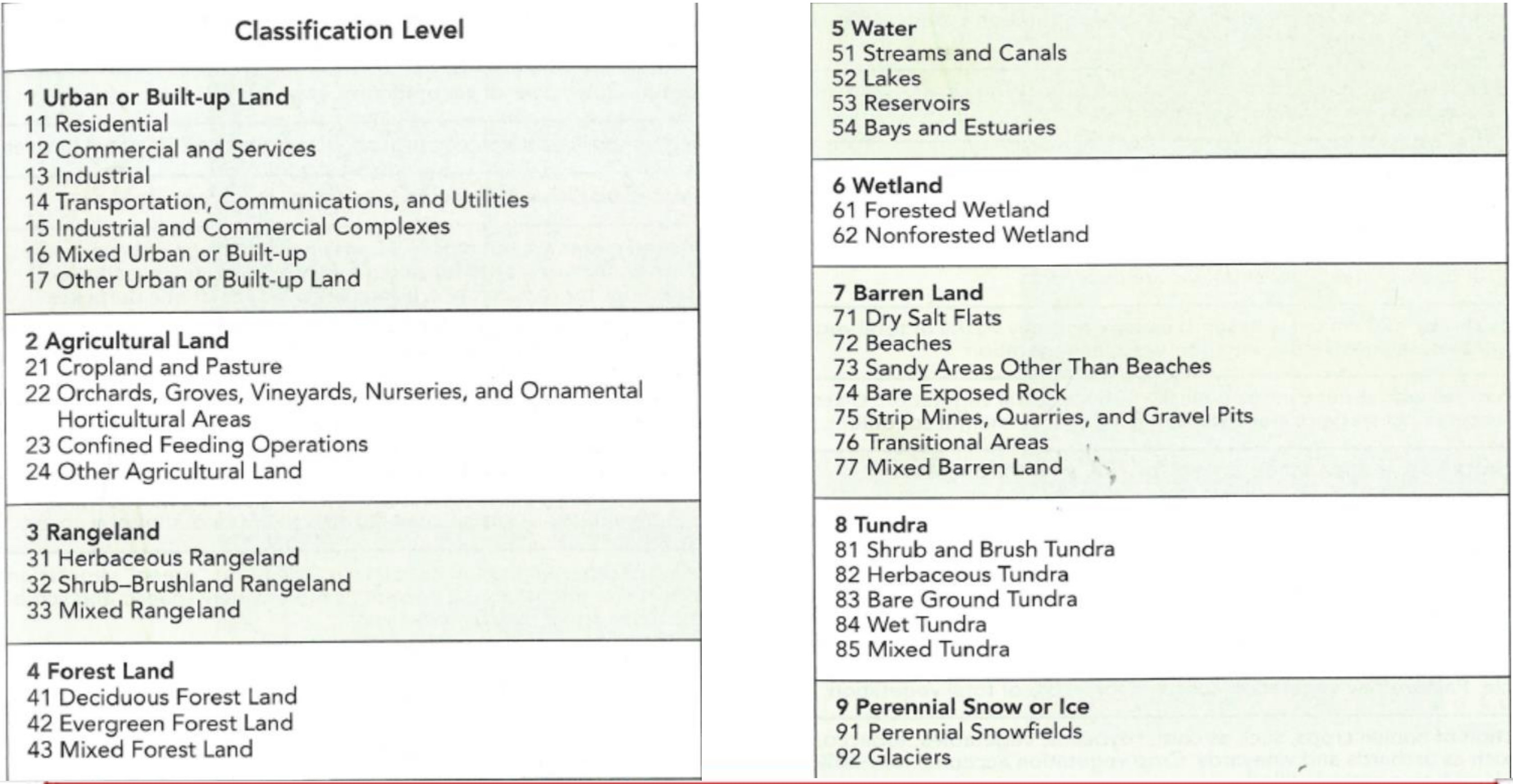
Common LULC Classification System Attributes

- Minimum mapping unit selected
  - The smallest size of an entity to be mapped as a discrete area
  - Using digital imagery it may be 2x2 or 3x3 pixels
- Accuracy
  - Overall accuracy minimum (e.g. 85%)
  - Accuracy of classes should be similar (e.g. no class < 80% accurate)
  - Repeatable results between interpreters/analysts
- Land use vs Land Cover
  - should be able to infer land use from land cover
  - Comparison to future LULC should be possible
  - Multiple uses of land should be recognized when possible

Classification Systems

- Classification systems (or schemes) are lists of labels describing thematic classes

USGS Level I & II classes (Jensen, 2015)



Classification Level
1 Urban or Built-up Land 11 Residential 12 Commercial and Services 13 Industrial 14 Transportation, Communications, and Utilities 15 Industrial and Commercial Complexes 16 Mixed Urban or Built-up 17 Other Urban or Built-up Land
2 Agricultural Land 21 Cropland and Pasture 22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas 23 Confined Feeding Operations 24 Other Agricultural Land
3 Rangeland 31 Herbaceous Rangeland 32 Shrub–Brushland Rangeland 33 Mixed Rangeland
4 Forest Land 41 Deciduous Forest Land 42 Evergreen Forest Land 43 Mixed Forest Land
5 Water 51 Streams and Canals 52 Lakes 53 Reservoirs 54 Bays and Estuaries
6 Wetland 61 Forested Wetland 62 Nonforested Wetland
7 Barren Land 71 Dry Salt Flats 72 Beaches 73 Sandy Areas Other Than Beaches 74 Bare Exposed Rock 75 Strip Mines, Quarries, and Gravel Pits 76 Transitional Areas 77 Mixed Barren Land
8 Tundra 81 Shrub and Brush Tundra 82 Herbaceous Tundra 83 Bare Ground Tundra 84 Wet Tundra 85 Mixed Tundra
9 Perennial Snow or Ice 91 Perennial Snowfields 92 Glaciers

Classification Systems: e.g. USGS

Level I

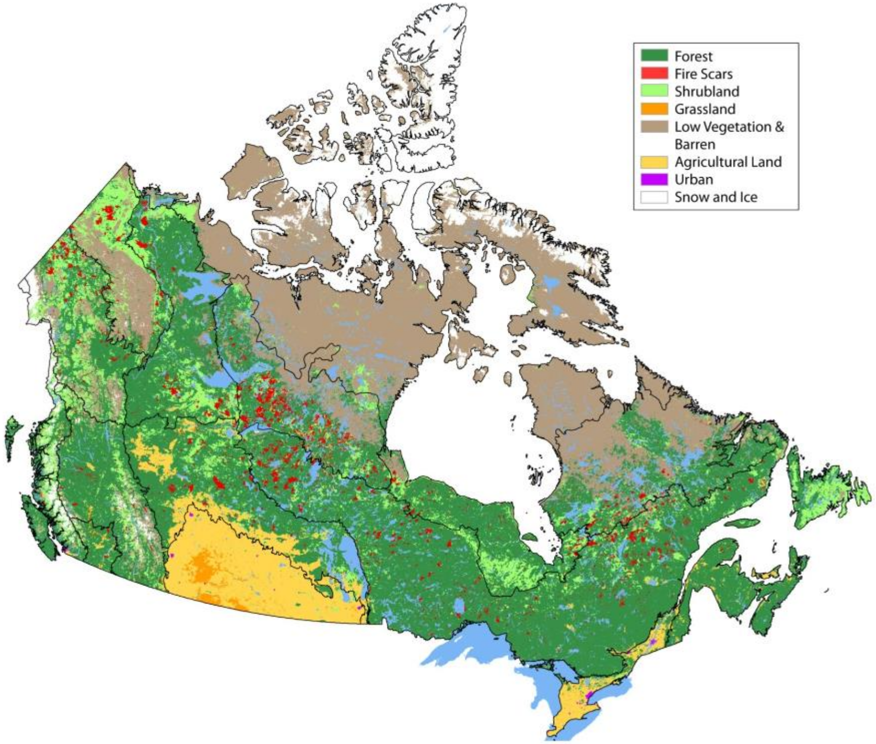
- Provincial to continental mapping
- Satellite imagery with large pixels
  - SPOT VGT, MODIS, AVHRR (Pixel size ~100m to >1km; Swath ~500-2000km)
  - OR Landsat, SPOT (20-30m pixels) in large budget mapping programs because requires many images
- MMU ≥ 150 ha (≥ 1 x 1km)

Level II

- Provincial scale (e.g. all of Ontario or regions) mapping
- Satellite imagery
  - SPOT, sometimes Landsat; or high altitude aircraft
    - Pixel sizes 10-30m; 60-200km swath
  - May use high resolution panchromatic band (2.5-10m pixels) fused with lower resolution multispectral bands (i.e., pansharpened imagery)
- MMU ~2.5 ha (~ 160 x 160m)

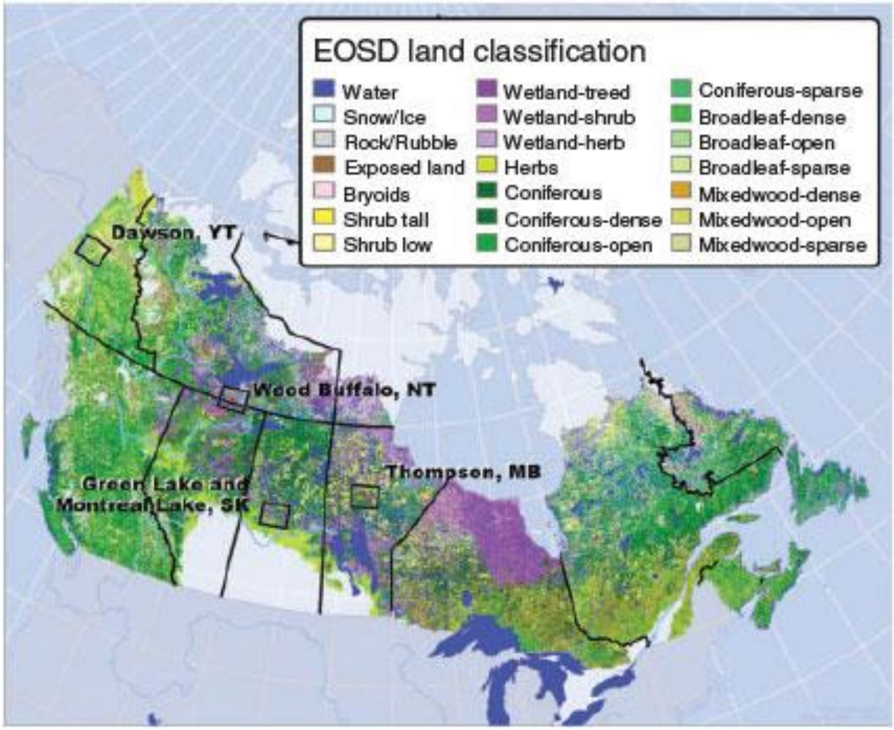
Canada Level I and II Land Cover Maps

~Level I



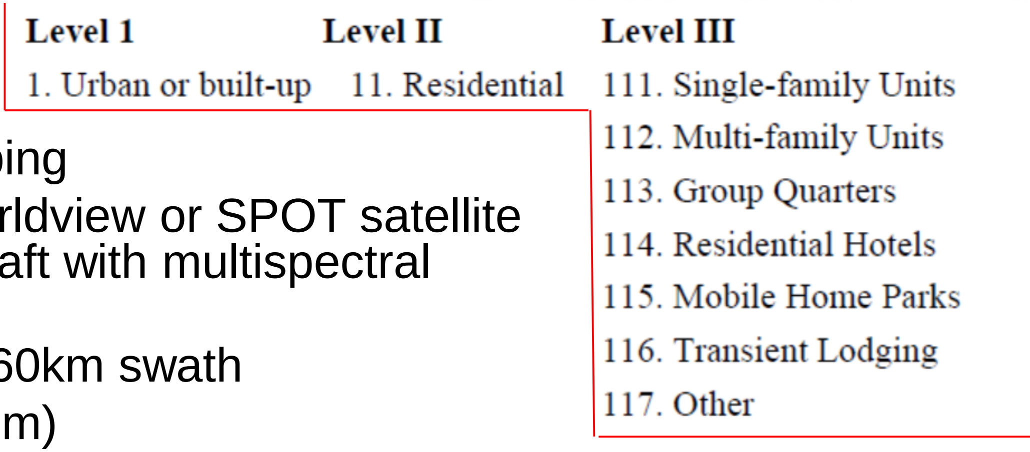
Latifovic and Pouliot. Canada Centre for Earth Observation and Mapping

~Level II, focused on forests



Wulder et al. Canadian Forest Service

Classification Systems: e.g. USGS



Level 1	Level II	Level III
1. Urban or built-up	11. Residential	111. Single-family Units
		112. Multi-family Units
		113. Group Quarters
		114. Residential Hotels
		115. Mobile Home Parks
		116. Transient Lodging
		117. Other

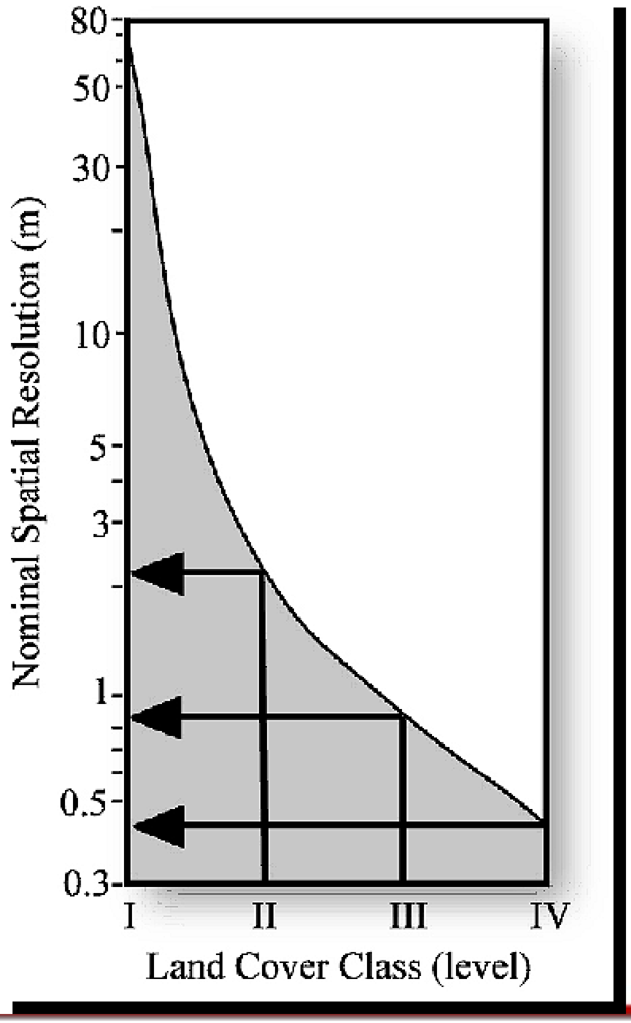
Level III

- County/town; local scale mapping
- Ikonos/GeoEye; Quickbird/Worldview or SPOT satellite imagery; Medium altitude aircraft with multispectral sensor or air photos
- Pixel sizes about <1 - 3m; 10-60km swath
- MMU ≈ 0.35 ha (about 60 x 60m)

Level IV

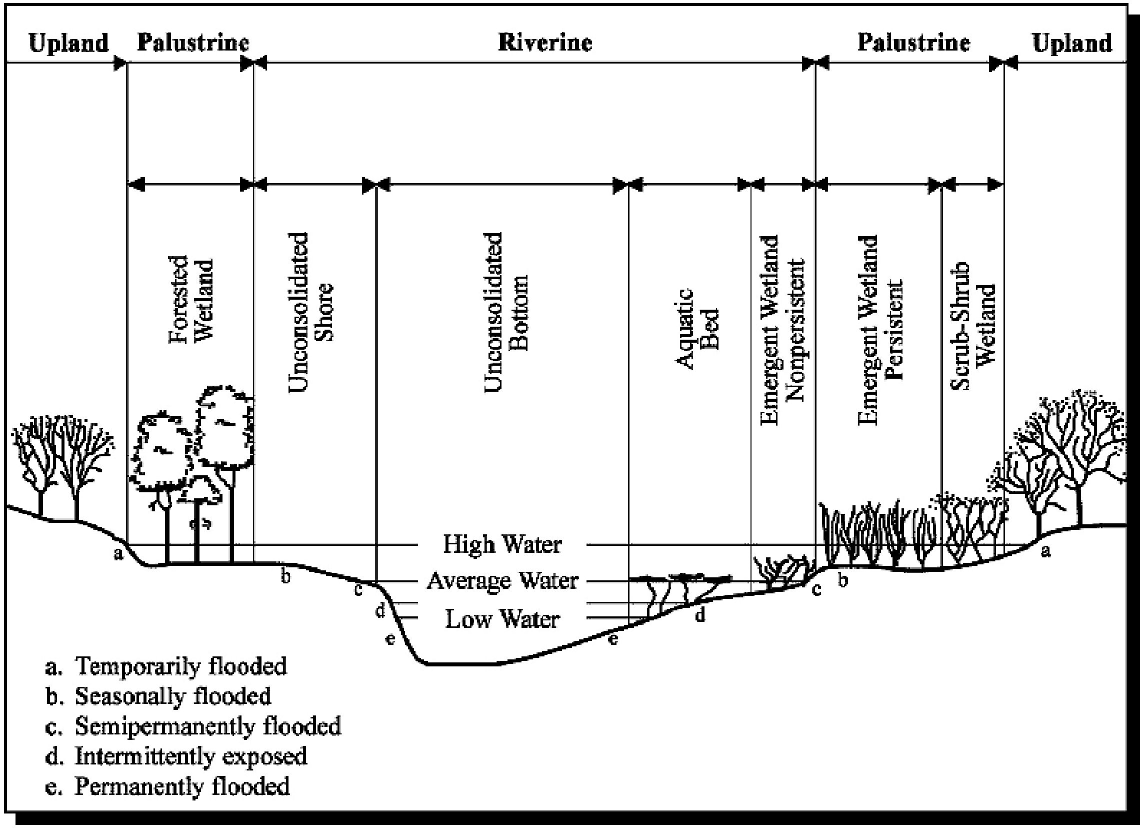
- Site specific developments/studies (often urban or infrastructure)
- Low altitude aircraft (including UAV) or panchromatic band of high res satellites
- Pixels sizes < 1m and often on the order of centimetres; 100m – 5km swath
- MMU: $\leq$ 0.1 ha (~ 10x10m -50x50m)

Image Resolution and Classification Attribute Detail



Jensen, 2015

Other Land Cover Classification Systems



A Wetlands Classification System

Jensen, 2015

How to visually interpret LULC in a manual classification?

- Use Elements of Interpretation
  - E.g., botryoidal texture may indicate Deciduous Forest

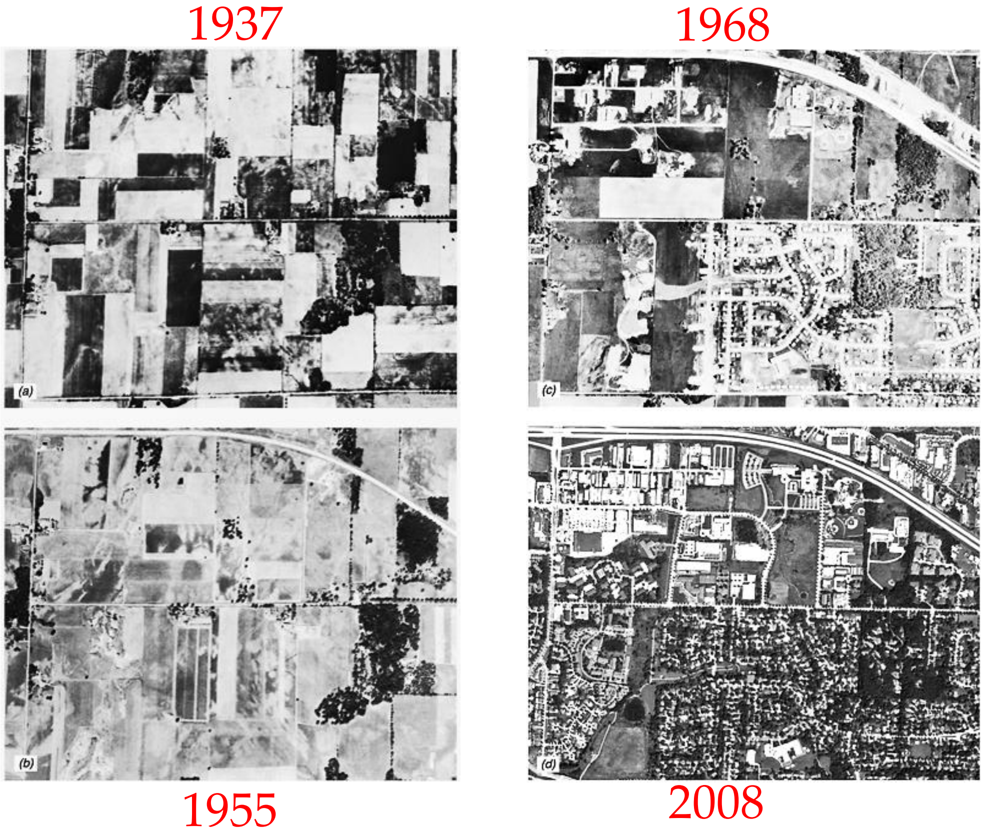
- Use context
  - E.g., square/rectangular shaped object in rural area may be an Agricultural Field

- Use local knowledge – context/association
  - E.g. Dow’s Lake: nearby is Carleton University – indicating classes of Lake (or Water) and Educational Area (or Institutional)

Example: Visual Interpretation of Urban LULC

- Based on tones, textures, size, shape, patterns (road and building layout), presence of vegetation, context/association
- E.g., Commercial
  - Long flat buildings; little vegetation; situated near main roads
- Industrial
  - Materials yards; large buildings and equipment set back from main roads and residential areas; smokestacks; little vegetation but a variety of surface brightnesses
- Older residential (single family, low density)
  - Individual houses visible; large trees and vegetation cover high; significant garden/yard size; street width low.

Madison, WI



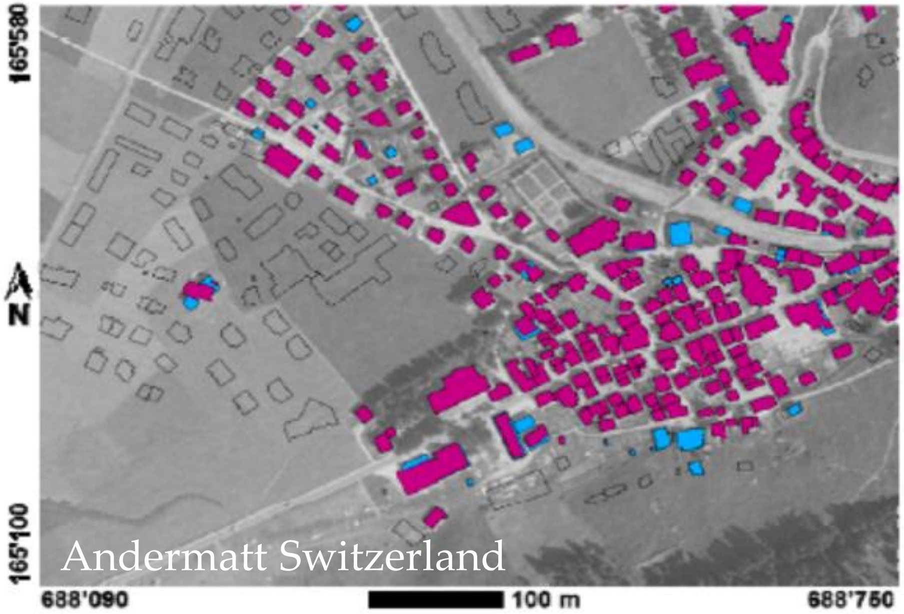
Lillesand et al., 2015

Example: Urban Change Digital Analysis

Nebiker, S., N. Lackemail and M. Deube. 2014. Building Change Detection from Historical Aerial Photographs Using Dense Image Matching and Object-Based Image Analysis. *Remote Sensing* 6(9): 8310-8336. http://www.mdpi.com/2072-4292/6/9/8310

- Historical Digital Surface Models (DSMs) derived from historical stereo air photos
- DSMs, the air photos themselves, cadastral information and a current Digital Terrain Model (DTM) used in building detection algorithm to delineate new buildings at each time period.

1959



2007

Visual LULC Classification (for Lab 4)

1. Obtain an image(s) that is appropriate for the lab (see instructions)
2. Decide on the classes to be mapped and an MMU
   - Consider the attributes given on previous slides in selecting your classes
3. Outline polygons covering each class; colour fill the polygons
   - Create a legend using these colours
4. Ensure all of the image is classified
5. Add required map items
   - Title, north arrow, scale

Graphics Sources

Jensen, J.R. 2007. *Remote Sensing of the Environment,* 2nd Edition, Prentice Hall.

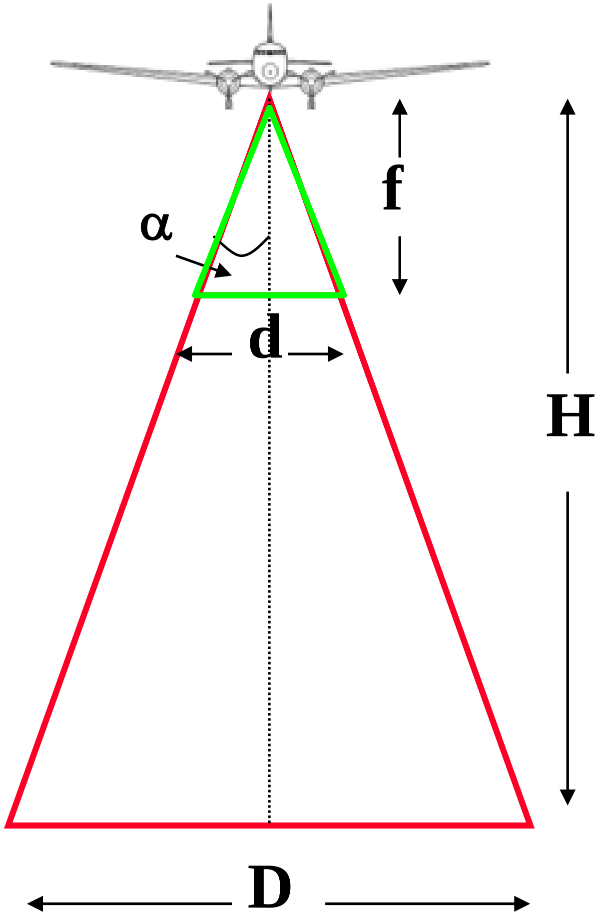
Dingle Robertson & King, 2011. Comparison of pixel-and object-based classification in land cover change mapping. International Journal of Remote Sensing 32(6): 1505-1529.

Unreferenced slides and graphics

D. King

Image Geometry, Flight Planning and Photogrammetry

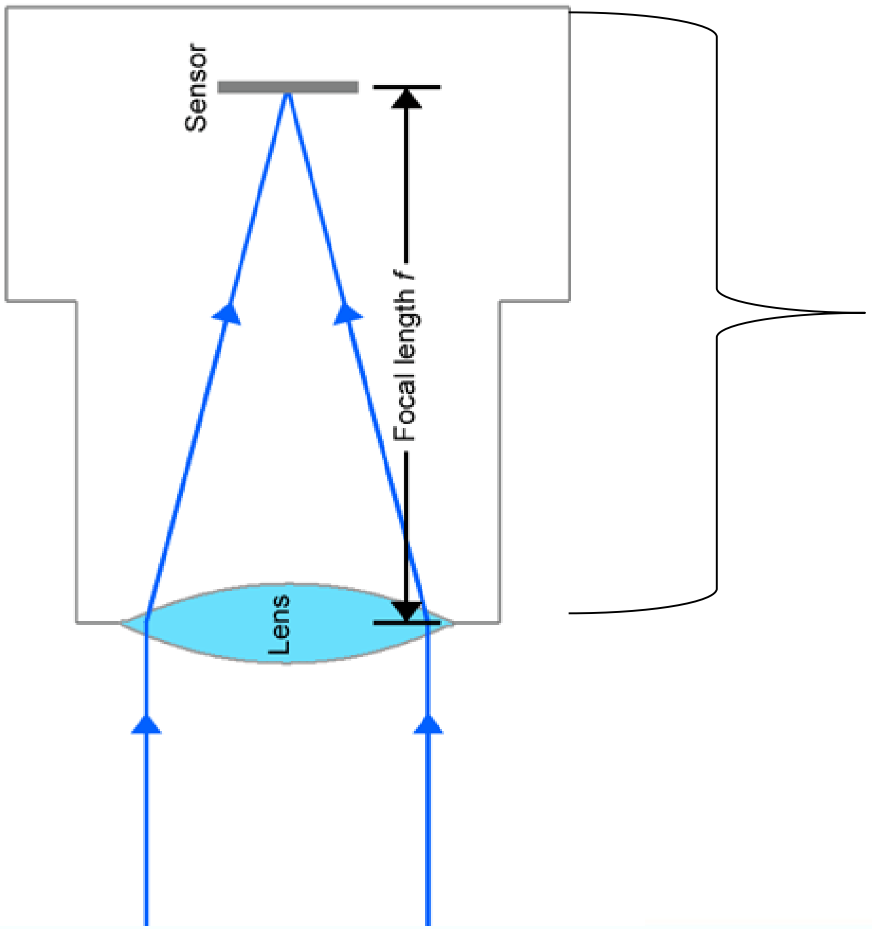
Basic Geometry of Optical Imagery



d = sensor size (mm)
f = lens focal length (mm)
D = ground coverage (m)
H = altitude above ground (m)
α = angle of view ± from nadir
2α = total angle of view

This geometry is constant for flat terrain and a vertical viewing sensor.

Focal length, f



Camera viewing downward

Relations between Sensor Geometry and Ground Imaging Geometry

- ‘Similar’ triangles have the same base : height ratio
  - i.e. in the large (red) and small (green) triangles

$$\frac{d}{f} = \frac{D}{H}$$

$$\therefore \frac{d}{D} = \frac{f}{H} = \text{image scale}$$

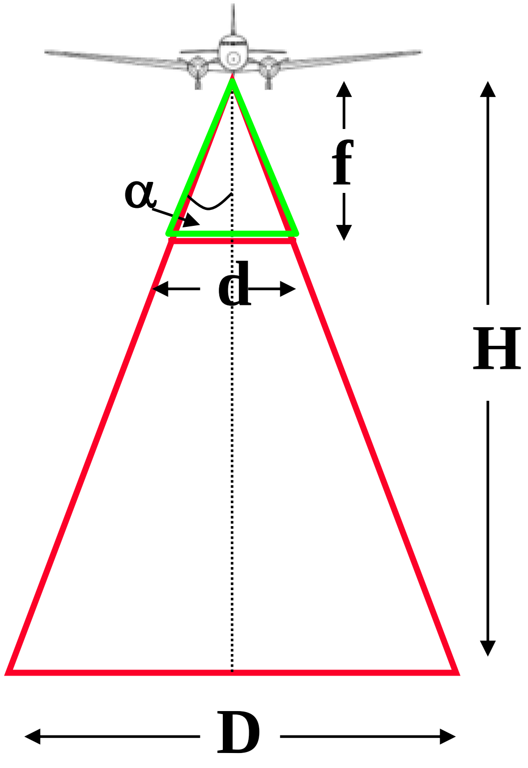


Image Scale

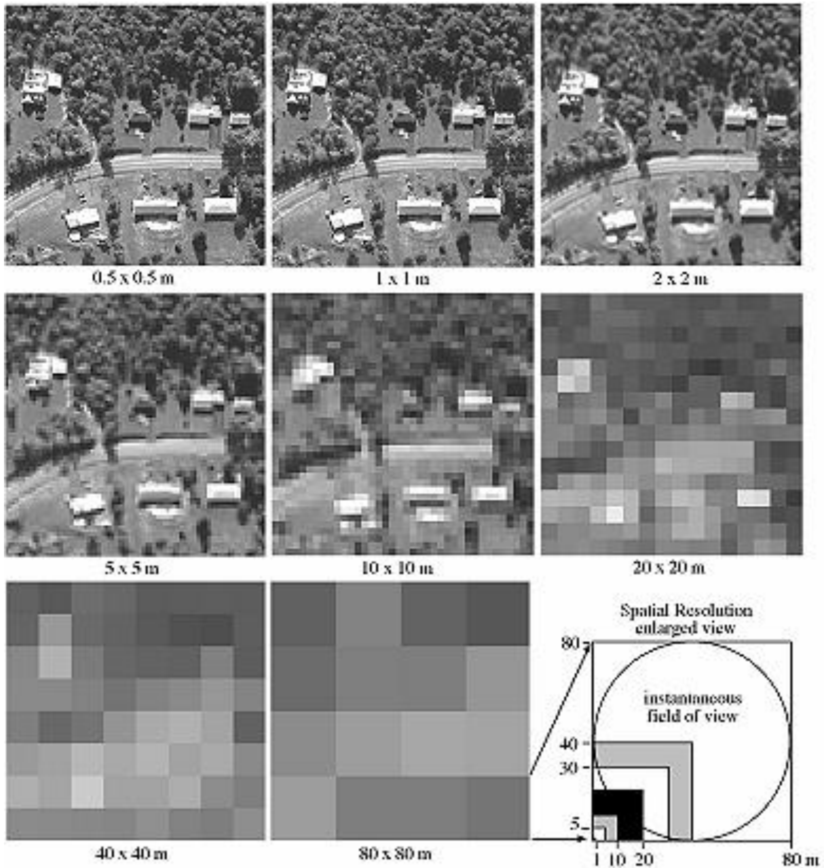
- Image scale can be expressed similarly to map scale:
  - Ratio of distance on image to distance on ground
  - 1:10,000 scale means 1 mm measured on image = 10,000 mm (10 m) on ground.
  - Sometimes use scale bar. Can zoom in and out and scale changes.

http://maps.ottawa.ca/geoottawa/

Scale of Digital Images

- Digital image scale is also expressed as pixel size and ground coverage
  - E.g. 50 cm nominal ground pixel size; 4 km x 2.5 km ground coverage
    - Pixel sizes of 25 cm -1 m common for airborne imagery; 1 m - 1 km for satellite imagery
  - Larger pixel size generally means > ground coverage per image and vice versa
- Can see some things at some scales and not at others.

Pixel Size

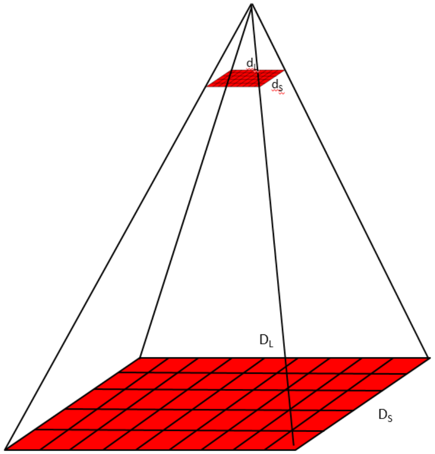


Jensen, 2007

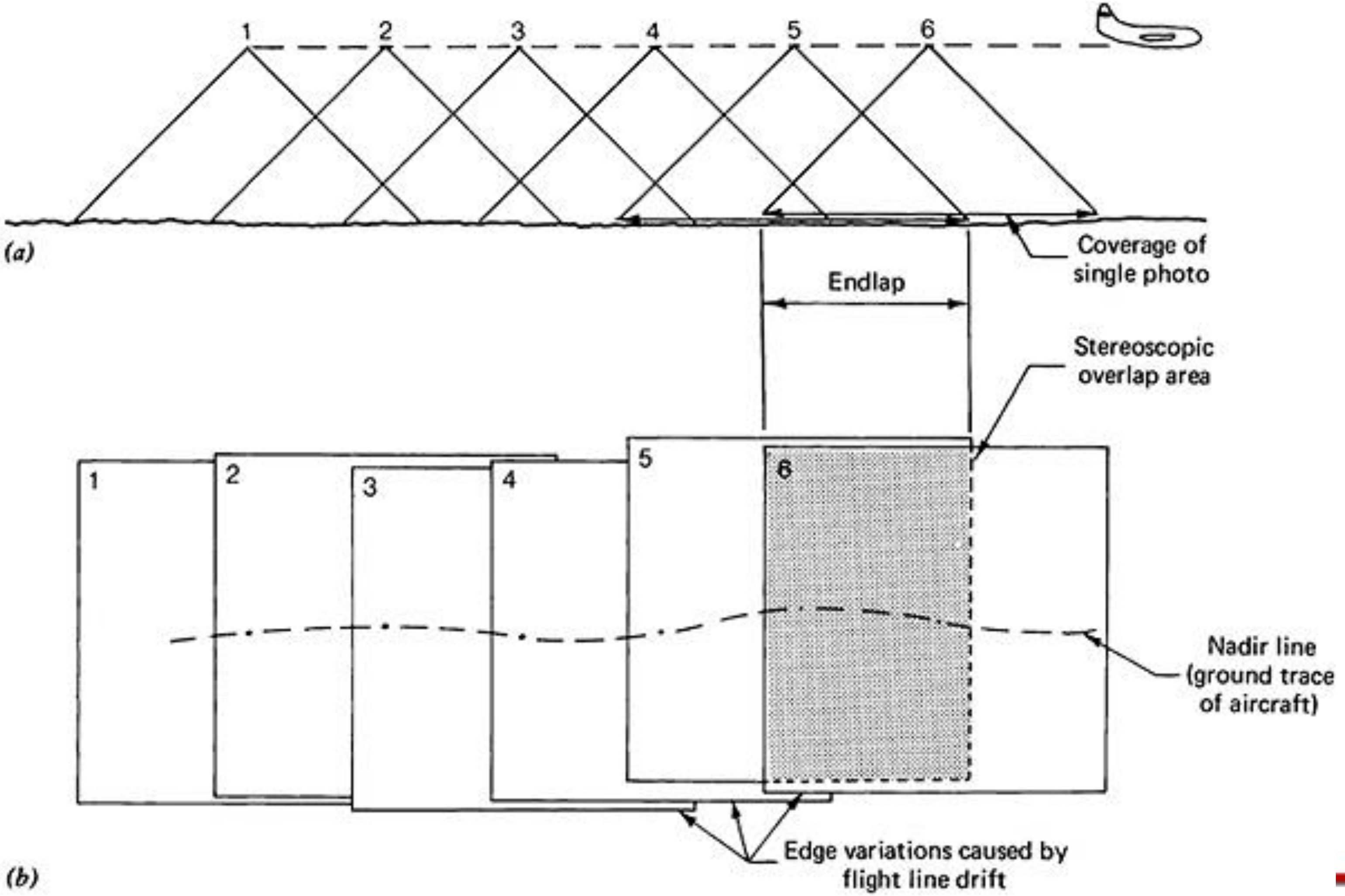
Flight Planning

- Usually f, d known; aircraft speed can be varied but typically known in knots, km/hr, or m/s
  - Commonly, with hardcopy air photos the question is to determine H and D given a required scale (e.g., 1:10,000)
  - Or, for digital cameras, determine H for a given ground coverage D and a given ground pixel size, or to detect a certain object size.

- Note: in the following examples, the images are square ($d_L = d_S$; $D_L = D_S$)
- Most consumer and many industrial digital camera detectors are rectangular ($d_L > d_S$; $D_L > D_S$)
- We'll start with square and then consider rectangular sensors in the lab

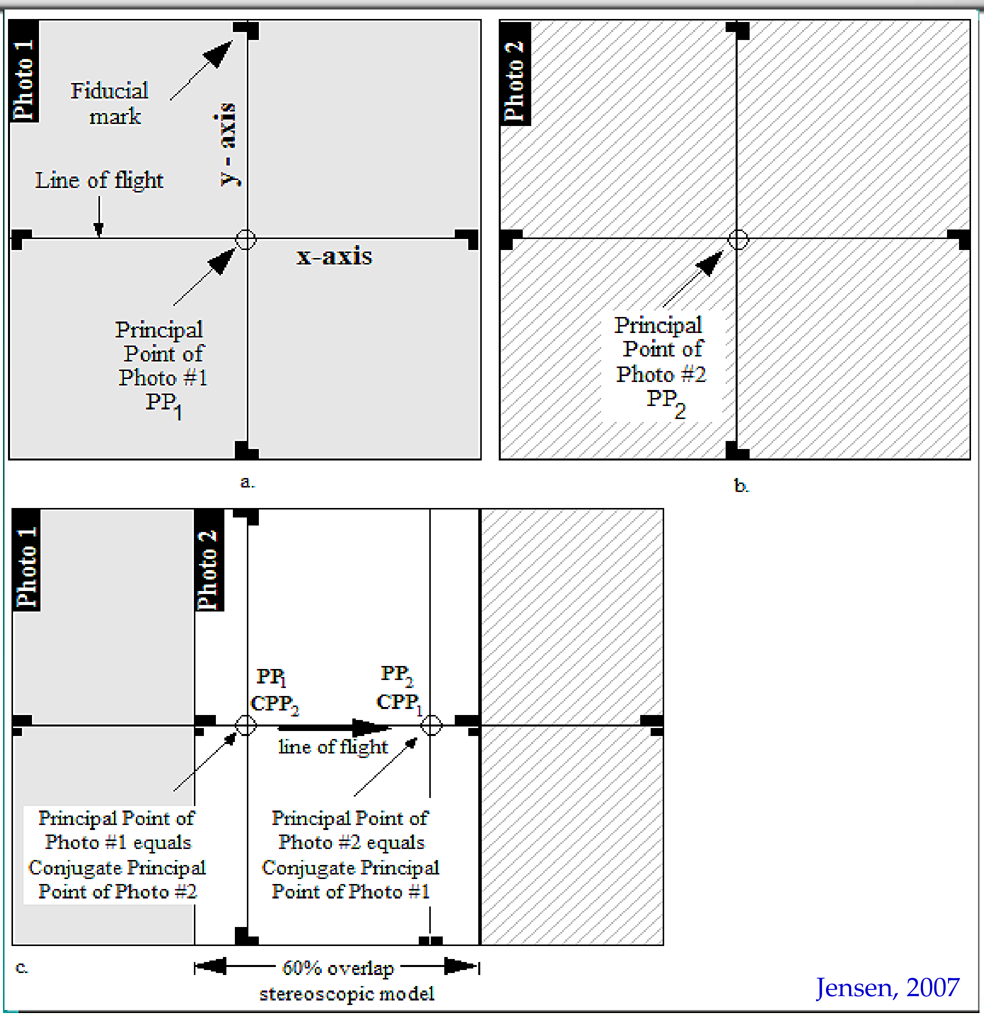


Flight Planning: Image Overlap



Lillesand *et al.*, 2015

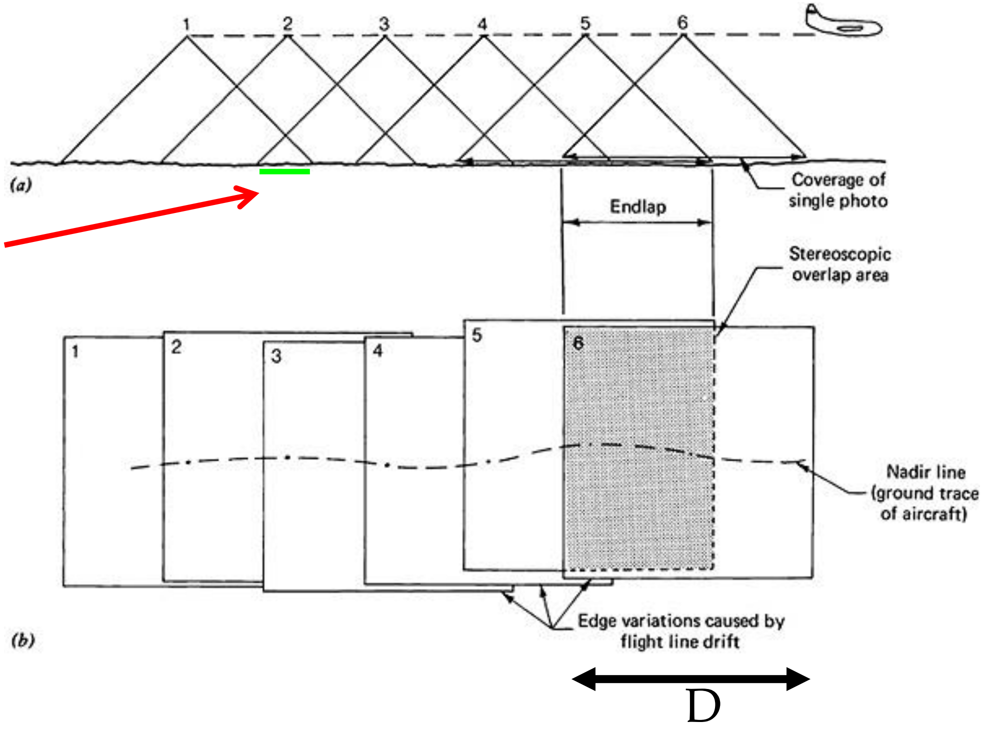
Flight Planning: Image Overlap



Jensen, 2007

Flight Planning: Image Overlap

- For good stereo and adequate ground coverage, forward overlap is often 55-65%
  - Allows small % overlap between 3 successive images
    - Used in mapping
- Once image is exposed covering D x D metres, aircraft moves ahead a distance equal to [100-%overlap] of D to take next image.
  - E.g., if overlap = 60%, plane moves ahead {100-60}D = 40% of D to take next image.



Lillesand *et al.*, 2015

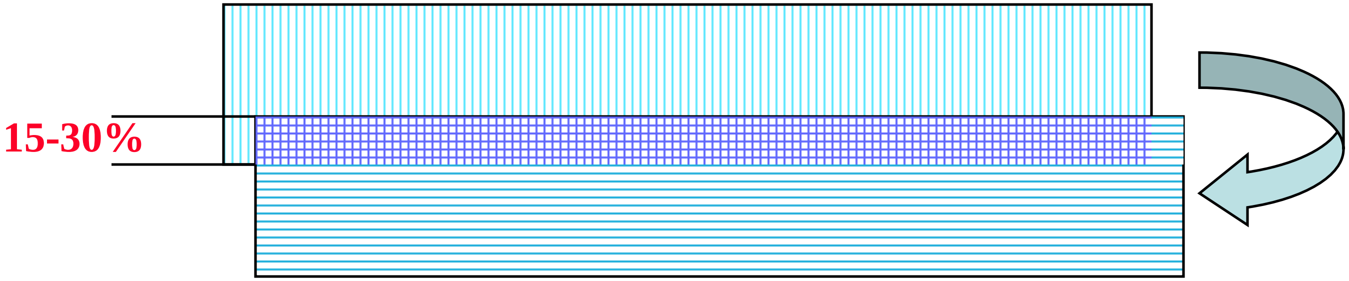
Flight Planning: Image Overlap

- Inter-relationship between ground coverage (D), distance and time between exposures, and plane speed
  - Need to calculate and acquire data precisely for good stereo overlap and coverage of target area
    - E.g. if D = 1 x 1 km, for 60% overlap, plane advances 40% of D between images = 0.4km = 400m.
      - If speed is 240km/hr = 66.67m/s, time between images is:

        400/66.67 = 6s.

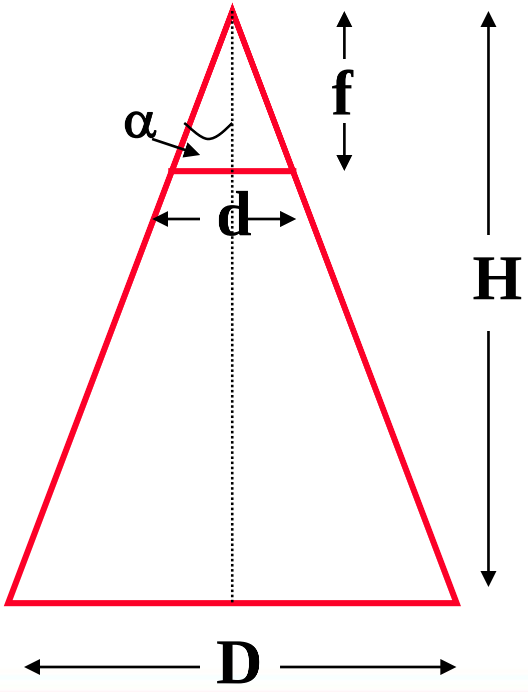
Flight Planning: Image Overlap

- Sidelap between flight lines



Flight Planning Calculations

First, recall the image geometry relations



d = sensor size (mm)
f = lens focal length (mm)
D = ground coverage (m)
H = altitude above ground (m)
α = angle of view ± from nadir
2α = total angle of view

d/D = f/H = image scale

Example Planning Calculations

(see also Lillesand et al.)

- Want to cover an area of 20km x 15km using 2.0m pixels, 30% sidelap and 60% forward overlap.

- Sensor (detector) size (d_L x d_S) is usually given in millimetres
  - e.g., 22.4 mm (d_L) x 18.2 mm (d_S)

- Number of pixels on the sensor is often known, e.g., 5000 X 3500

- Focal length usually known, e.g. 14mm

Example Planning Calculations

1. Calculate coverage D_L x D_S

- 2.0 m pixel size x 5000 pixels = $\underline{10{,}000\text{m}}$ = D_L
- 2.0 m pixel size x 3500 pixels = $\underline{7{,}000\text{m}}$ = D_S

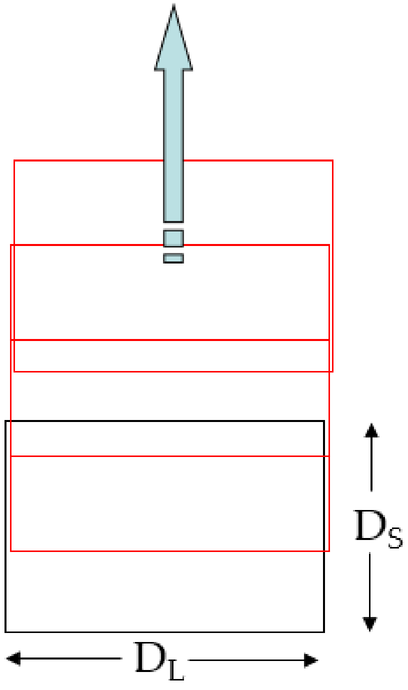
2. Determine Flying Height

$f/H = d/D$

$$\frac{14\text{mm}}{H} = \frac{22.4\text{mm}}{10000\text{m}} \qquad H = 14(10000)/22.4 = \underline{6{,}250\text{m}}$$

Example Planning Calculations

3. Calculate # photos per line



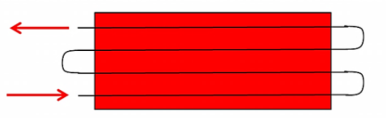
- Usually orient the camera with long dimension perpendicular to the flight line to minimize # of turnarounds

- If forward overlap of 60%, photo centres are shifted by 40% or 0.4 (of D_S) as aircraft advances.
    - i.e. 0.4 x 7,000 = 2,800m between photo centres along a given flight line
        - This distance is called the Air Base (B).

Example Planning Calculations

Photos per line (cont’d)

– For the given area to be mapped, fly along the long dimension to reduce the number of times the aircraft has to turn around



– 20,000m / 2800m advance per photos

= 7.14 ‘spaces’ between photos

– Add 1 photo at beginning and 1 photo at end of each line to ensure stereo at both ends = 9.14 photos

– Round up to <u>10 photos</u> for complete coverage

  - can’t have fractions of photos.

Example Planning Calculations

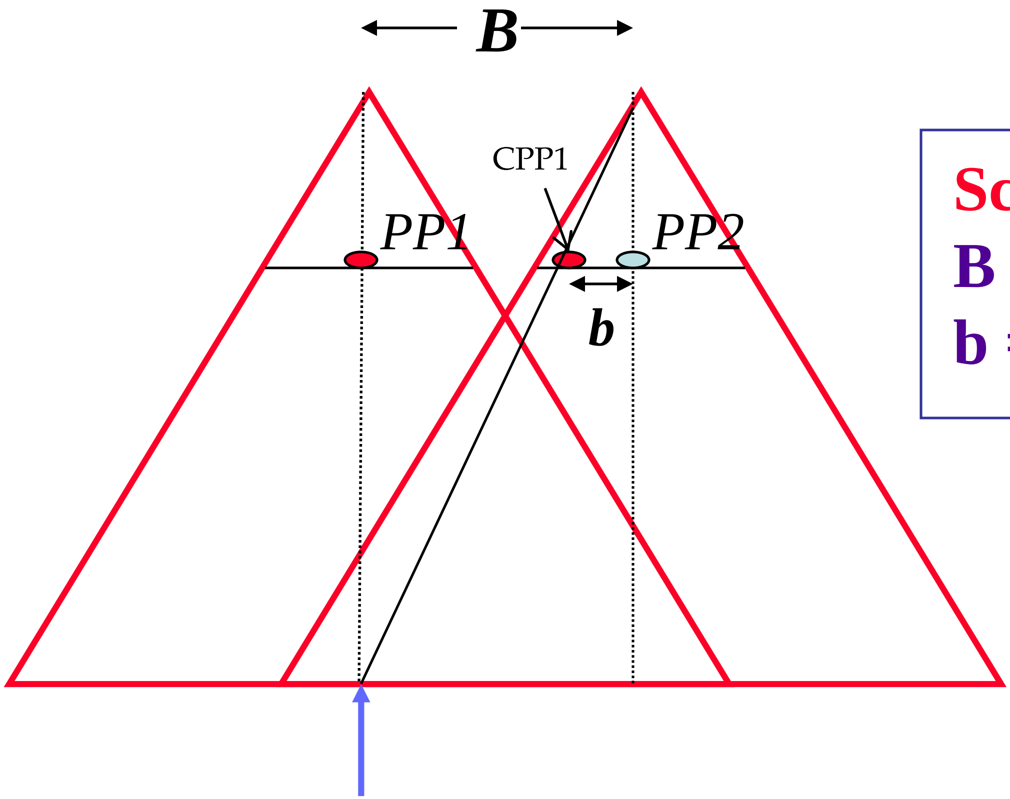
4. Calculate # flight lines

- Given 30% sidelap, for each new flight line, the aircraft shifts over by $0.7 \times D_L = 0.7 \times 10000\text{m} = 7000\text{m}$
- 15000m / 7000m = 2.14 ‘spaces’ between lines
- For lines, only add 1 line to ensure full coverage = 3.14
- Round up to nearest integer = 4 lines

5. Calculate total photos to cover the area

- # photos/line x # lines = total # photos to cover the area
  - Can work out costs if image and flight costs known
  - Software is available that automatically determines flight lines and exposure positions if certain inputs known
  - Later we will learn about line scanners

One More Scale Relation



PP1 appears on both images

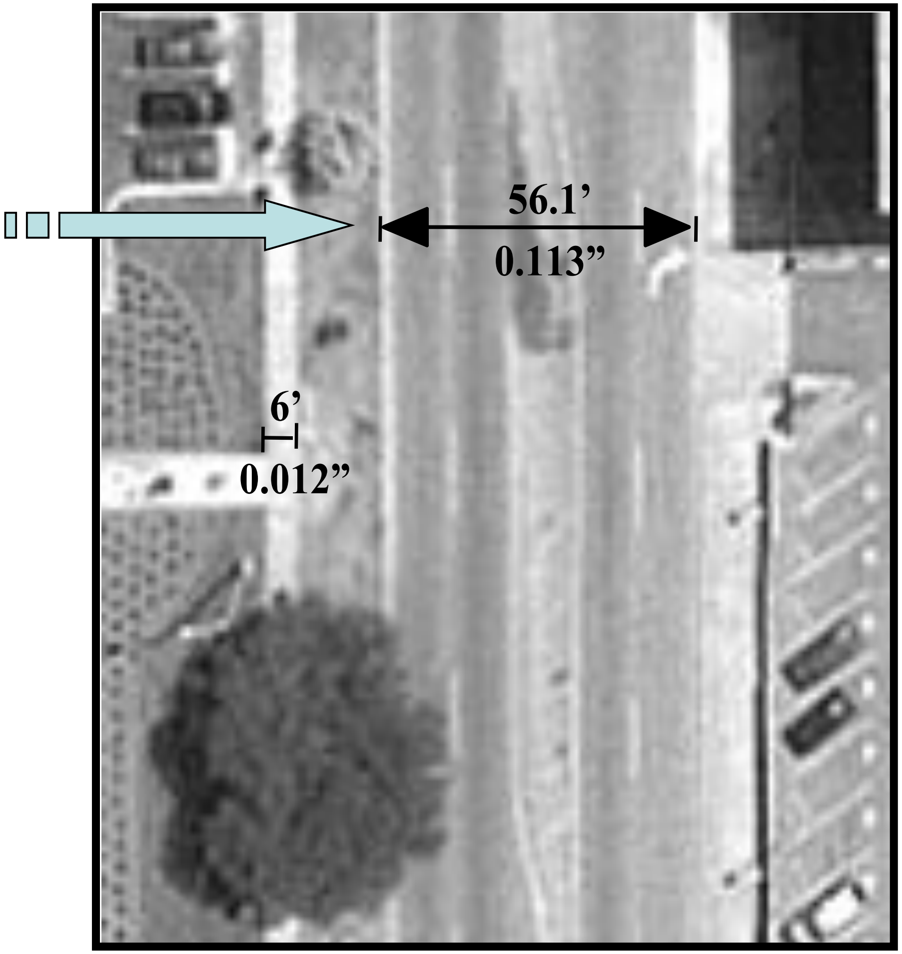
Scale = b / B

B = air base (m)

b = image base (m)

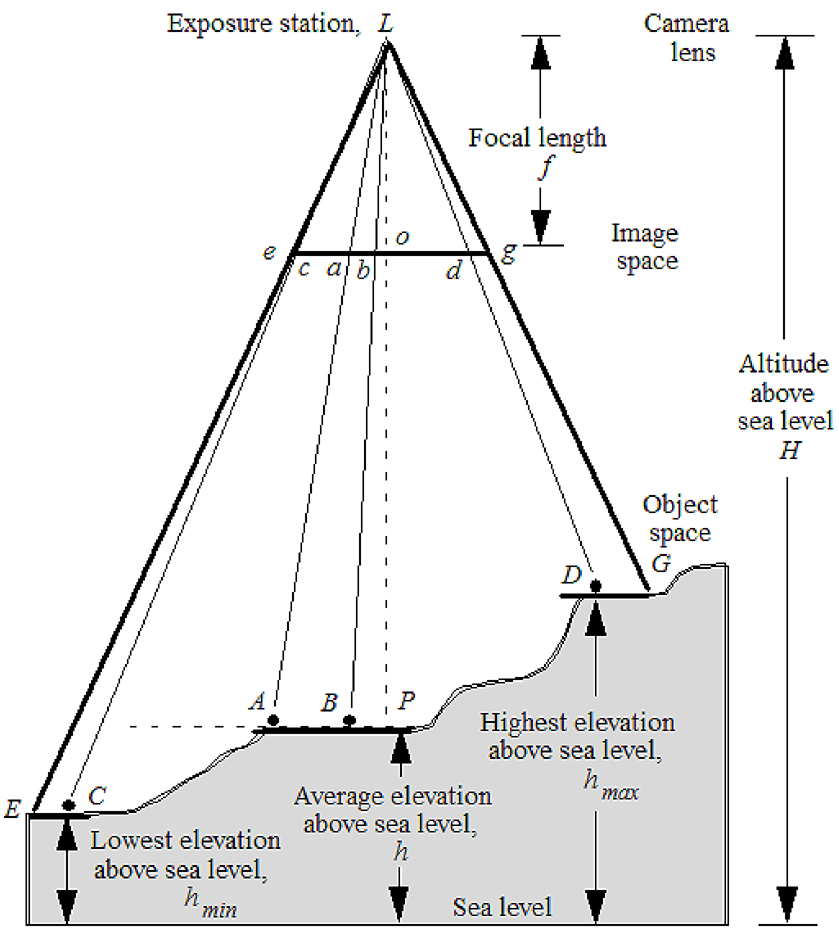
Photogrammetry

- For vertical photos of flat terrain, once image scale is known, can measure distances on image and convert to distances on ground
- *Photogrammetry* = The science of determining the exact 3-d geometry of stereo images and using the images to measure distances, areas, heights + create topo maps, DEMs and ortho-images
  - Includes corrections for platform rotation, image motion during exposure, topographic distortions, etc.
  - Processing is done in stereo workstations



Jensen, 2007

Image Geometry in Variable Terrain

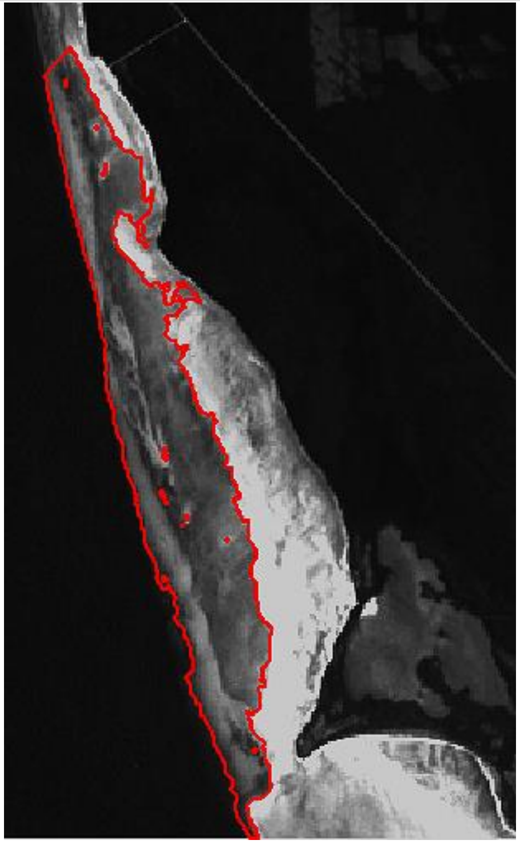


Jensen, 2007

- Scale or pixel size vary across the image.
- Often use the mean elevation of the area to give a mean flying height and mean (or 'nominal') image scale.

Area Measurement on Images

- Measure delineated areas by counting pixels within the polygon and multiplying by the nominal ground pixel size



Reef measurement (398m^2) from SPOT image. Cozumel Island, Mexico

Jensen, 2007

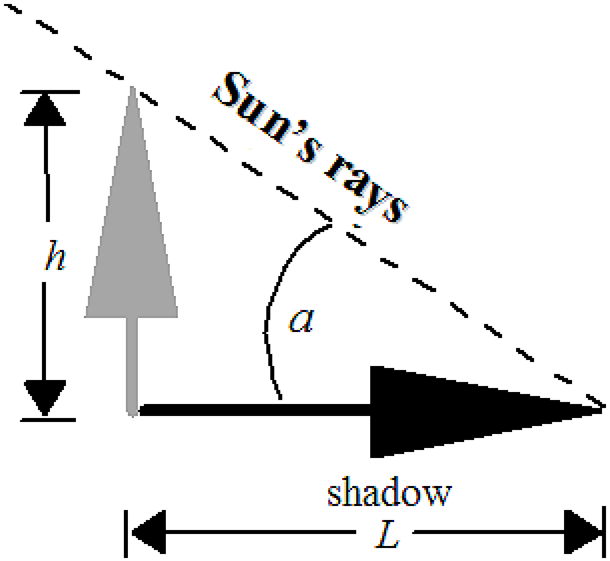
Height Measurements from Single Images
Shadow Length

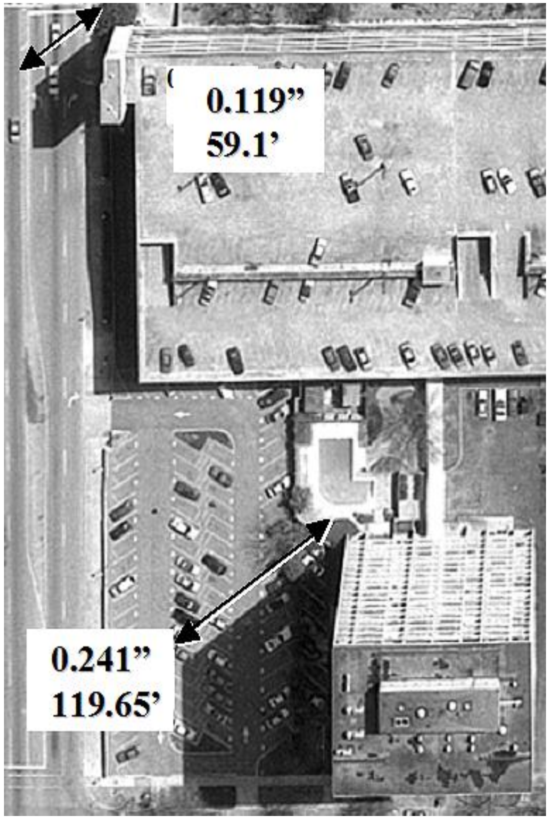
From shadow length

$$\tan a = \frac{\text{opposite}}{\text{adjacent}}$$

$$= \frac{\text{height, } h}{\text{shadow, } L}$$

$$h = L \times \tan a$$

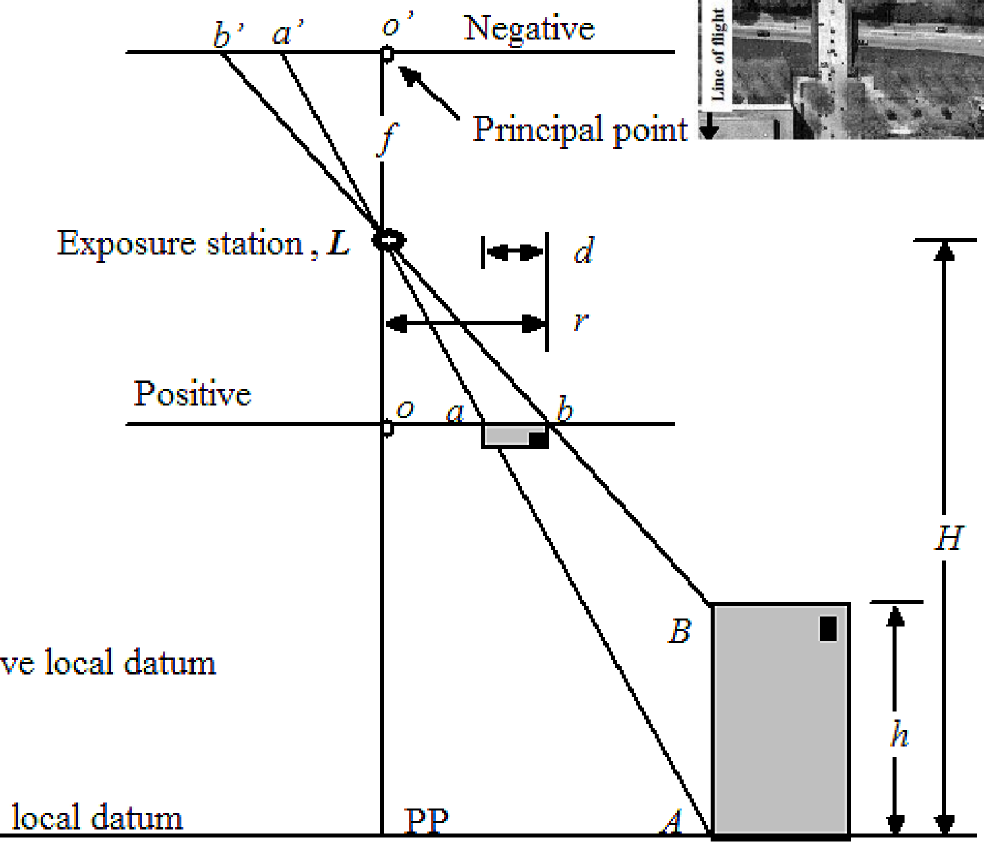




Jensen, 2007

Height Measurements from Single Images
Relief Displacement

Jensen, 2007



$$\frac{h}{H} = \frac{d}{r}$$

$$\therefore\ h = \frac{d \times H}{r}$$

$r = 2.23$ in.
$d = 0.129$ in.
$H = 2978.5$ ft above local datum
$h = 172$ ft

<u>Relief Displacement</u>: of 3-d objects

Height Measurements from Stereo Images
Parallax

- Using Parallax
  - Parallax = The shift in position on the x-axis of a point from one image to the next in a stereo pair
    - Measured with respect to the image origin (principal point)
- Measure parallax for top of object and repeat for bottom of object

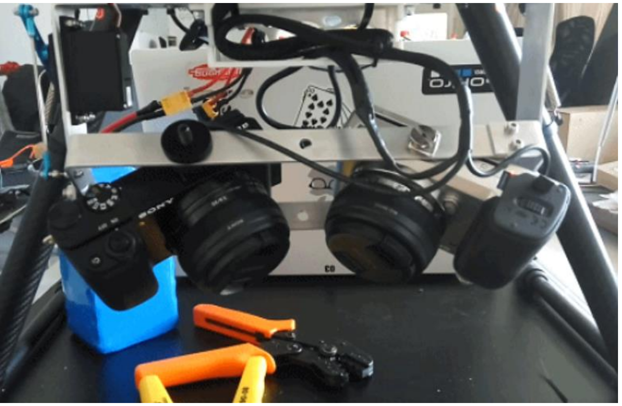
$$h = (H)[(dP)/(P + dP)]$$

- h = height of object
- H = flying height above the base of the object
- P = parallax measured for the bottom of the object
- dP = difference in parallax between the top and the bottom of the object
  - The method is a bit more complex than this but can be found in many texts.

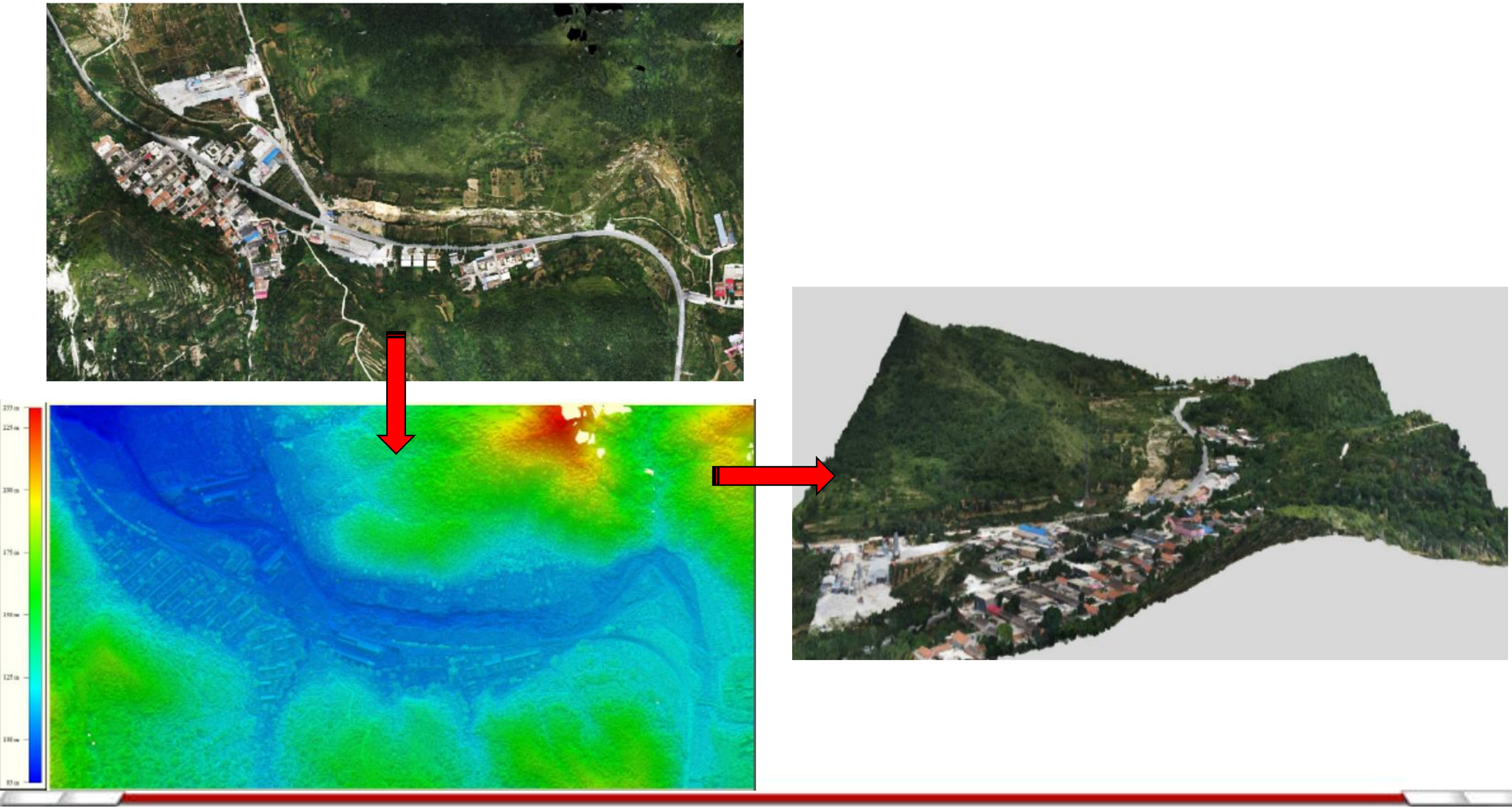
Height Measurements from Stereo Images Creating DEMs

- Most DEMs are created from stereo images by measuring the parallax at many (millions) matching pixels in the two images.
  - Matching pixels in two stereo images can be automatically extracted using algorithms that analyze the correlations between local areas in windows of a given size
    - i.e., Moving the window in one image around until the correlation of pixel brightnesses in that window vs. brightnesses in the window in the other image window is maximized. The centre pixels in each image are then selected as a matching pair.
    - Some algorithms also use edge and texture information in this local area correlation analysis.
- As not all pixels in the two images can be matched in this process, parallax is measured only at the matched points and elevation for the remaining points is determined by interpolation to produce the DEM
- The complete process is more complex and involves matching the geometry of the 2-3 stereo images and some other steps.
- See the process for stereo Worldview-3 images with PCI Geomatica at: https://www.youtube.com/watch?v=0SIKT-17x3E&feature=youtu.be

UAV-based Photogrammetry

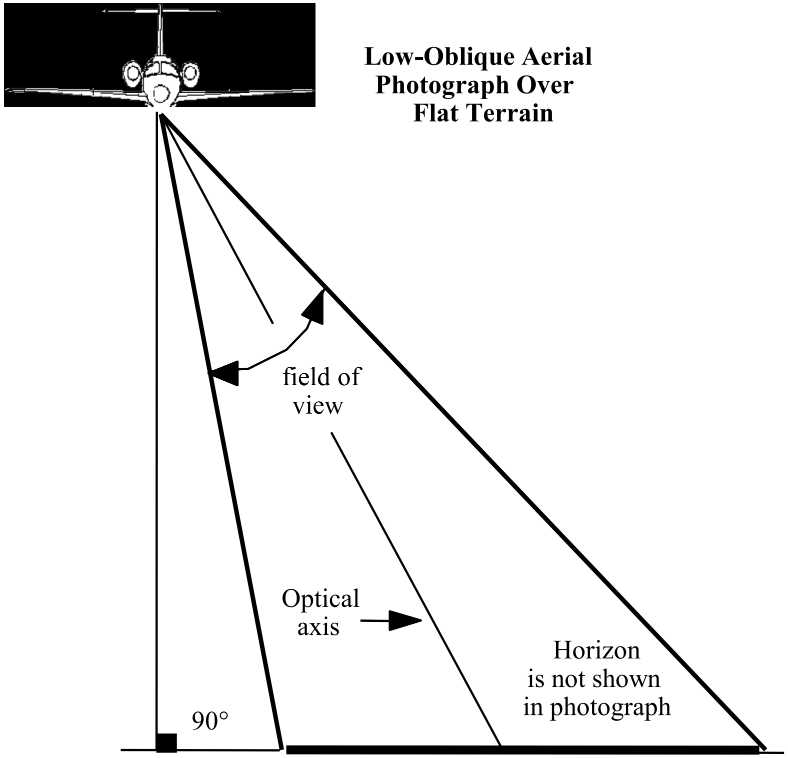


UAV-based Photogrammetry



Oblique Airborne Images

- Have many uses in visual analysis but oblique photogrammetry is more complex



Low-Oblique Aerial Photograph Over Flat Terrain

Corning Museum of Glass, NY
http://www.pictometry.com