Introduction

- Curtis Woodcock
  - Professor
  - Department of Geography and Environment
  - Boston University
  - PhD (Geography, UCSB)

- Areas of Interest: Remote Sensing – particularly of land cover and land use change and forests, focusing on the use of optical data (particularly from the Landsat series of satellites)

- Fun things I’ve been fortunate enough to get to do:
  - Extensive work in the Sierra Nevada Mountains of California (in support of forest vegetation mapping and monitoring)
  - Research projects in China, Egypt, Turkey, the Black Sea region, Australia
  - Member of the Landsat Science 7 Team
  - Member of the Land Cover Characteristics and Changes Implementation Team of GOFC/GOLD
Presentation Outline

Background on remote sensing
- optical remote sensing
- the Landsat satellites

Prior projects
- Egypt: Land Reclamation and Desertification
- China: Urbanization
- Turkey: Agricultural Development and Climate

Professional Information
- Who uses remote sensing?
- What kinds of people comprise the remote sensing community?
Sources of Electromagnetic Energy

“Optical Remote Sensing” uses measurements of reflected solar radiation
Absorption of the Sun's Incident Electromagnetic Energy in the Region from 0.1 to 30 μm by Various Atmospheric Gases

Jensen, 2000
Dominant Factors Controlling Leaf Reflectance

Water absorption bands:
- 0.97 μm
- 1.19 μm
- 1.45 μm
- 1.94 μm
- 2.70 μm
Hemispherical Reflectance, transmittance, and Absorption Characteristics of Big Bluestem Grass
Chronological Launch and Retirement History of the Landsat Satellite Series

Launch and Retirement Dates:
- Landsat 1 - July 23, 1972, to January 6, 1978
- Landsat 2 - January 22, 1975, to July 27, 1983
- Landsat 3 - March 5, 1978, to September 7, 1983
- Landsat 4 - July 16, 1982
- Landsat 5 - March 1, 1984
- Landsat 6 - October 5, 1993, did not achieve orbit
- Landsat 7 - April 15, 1999
Launch of Landsat 7 on April 15, 1999 from Vandenberg Air Force Base in California (on a Delta rocket)
## Landsat Sensor Characteristics

(Note in particular Landsat TM and ETM+)

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Bandwidths</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>LANDSATs 1-2</td>
<td>RBV</td>
<td>(1) 0.48 to 0.57</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) 0.58 to 0.68</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3) 0.70 to 0.83</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>(4) 0.5 to 0.6</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5) 0.6 to 0.7</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6) 0.7 to 0.8</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7) 0.8 to 1.1</td>
<td>79</td>
</tr>
<tr>
<td>LANDSAT 3</td>
<td>RBV</td>
<td>(1) 0.505 to 0.75</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>MSS</td>
<td>(4) 0.5 to 0.6</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5) 0.6 to 0.7</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6) 0.7 to 0.8</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7) 0.8 to 1.1</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(8) 10.4 to 12.6</td>
<td>240</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Bandwidths</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>LANDSATs 4-5</td>
<td>MSS</td>
<td>(4) 0.5 to 0.6</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5) 0.6 to 0.7</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6) 0.7 to 0.8</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7) 0.8 to 1.1</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>TM</td>
<td>(1) 0.45 to 0.52</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) 0.52 to 0.60</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3) 0.63 to 0.69</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4) 0.76 to 0.90</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5) 1.55 to 1.75</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6) 10.4 to 12.5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7) 2.08 to 2.35</td>
<td>30</td>
</tr>
</tbody>
</table>

| LANDSAT 7    | ETM⁺   | (1) 0.45 to 0.52 | 30         |
|              |        | (2) 0.52 to 0.60 | 30         |
|              |        | (3) 0.63 to 0.69 | 30         |
|              |        | (4) 0.76 to 0.90 | 30         |
|              |        | (5) 1.55 to 1.75 | 30         |
|              |        | (6) 10.4 to 12.5 | 60         |
|              |        | (7) 2.08 to 2.35 | 30         |
|              |        | PAN 0.50 to 0.90 | 15         |

*Important!*
“Polar” orbits allow for global coverage – the descending part of the orbit is “sun synchronous” and the ascending part is on the dark side of the planet.
Landsat's Unique Niche Leads to a High Resolution Global Seasonal Archive Capability

**AVHRR, MODIS**
- spatial resolution, 250m, 500m, 1000m
- spectral coverage, VIS, NIR, SWIR, MWIR, TIR
- calibrated @ ≤ 5% absolute
- global coverage, 2 days
- nadir only

**Landsat**
- spatial resolution, 15m, 30m
- spectral coverage, VIS, NIR, SWIR, TIR
- calibrated @ ≤ 10% absolute
- 16 day orbital repeat
- seasonal global coverage capability
- nadir only

**IRS**
- spatial resolution 36m, 72m
- spectral coverage, VIS, NIR
- relative calibration
- 22 day orbital repeat
- nadir only

**SPOT**
- spatial resolution 10m, 20m
- spectral coverage, VIS, NIR
- relative calibration
- 26 day orbital repeat
- pointable, stereo capability

**IKONOS**
- spatial resolution 1m
- spectral coverage, panchromatic
- calibrated @ ≤ 10% absolute
- global coverage, years to ∞
- pointable, stereo capability
Landsat Thematic Mapper Spectral Bands

Band 1 (Blue)

Band 7 (Mid IR)
Landsat Thematic Mapper Spectral Bands

Band 2 (green)

Band 5 (mid IR)
Landsat Thematic Mapper Spectral Bands

Band 3 (red)  Band 4 (NIR)
Landsat Thematic Mapper Spectral Bands

Notice the blurry nature of the image. This is due to 2 effects: (1) the bigger size of the pixels (120m instead of 30m), and (2) because surface temperature does not vary over such short distances as dramatically as surface reflectance. (Dark is low temperature, bright is high temperature)
Let’s muck with your sense of color!

We can make a color composite out of 3 of the spectral bands – using an additive color scheme. In this approach, one TM Band is put in each of the 3 primary colors: red, green, and blue (in that order). So we can make a “true” color composite, by matching the TM Bands that our eyes see as those colors, with the color guns in the computer. So in the example to the left:

Landsat TM Band 3 = red
Landsat TM Band 2 = green
Landsat TM Band 1 = blue

The higher the reflectance (the brighter it appears in black and white) the stronger the contribution of the color.
Let’s muck with your sense of color! (continued)

In this “false” color composite, we have used wavelength ranges outside those our eyes can see!
We have put the Near Infrared band (Band 4) into the red color gun on the computer, the red spectral band in the green color gun, and the green spectral band in the blue color gun:
Landsat TM Band 4 = red
Landsat TM Band 3 = green
Landsat TM Band 2 = blue

One reason for doing this is to help us visualize reflectance in the wavelengths we can’t see with our eyes!

This particular color combination is very common – where vegetation appears red.
You have lots of control over the appearance of the images!

Landsat 435

Landsat 453
Landsat's Unique Niche Leads to a High Resolution Global Seasonal Archive Capability

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Spatial Resolution</th>
<th>Spectral Coverage</th>
<th>Calibration</th>
<th>Repeat Cycle</th>
<th>Niche</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR, MODIS</td>
<td>250m, 500m, 1000m</td>
<td>VIS, NIR, SWIR, MIR, TIR</td>
<td>≤ 5% absolute</td>
<td>2 days</td>
<td>Nadir only</td>
</tr>
<tr>
<td>Landsat</td>
<td>15m, 30m</td>
<td>VIS, NIR, SWIR, TIR</td>
<td>≤ 10% absolute</td>
<td>16 days</td>
<td>Seasonal global coverage capability, Nadir only</td>
</tr>
<tr>
<td>IRS</td>
<td>36m, 72m</td>
<td>VIS, NIR</td>
<td>Relative calibration</td>
<td>22 days</td>
<td>Nadir only</td>
</tr>
<tr>
<td>SPOT</td>
<td>10m, 20m</td>
<td>VIS, NIR</td>
<td>Relative calibration</td>
<td>26 days</td>
<td>Pointable, Stereo capability</td>
</tr>
<tr>
<td>IKONOS</td>
<td>1m</td>
<td>Panchromatic</td>
<td>≤ 10% absolute</td>
<td>Years to ∞</td>
<td>Pointable, Stereo capability</td>
</tr>
</tbody>
</table>
MODIS: System Characteristics

- **MODIS Instrument Characteristics**
  - 36 spectral bands, VNIR, SWIR, TIR (0.4–14 μm)
    - Seven specifically designed for land observation
  - Spatial resolutions at 250-, 500-, and 1000-m (nadir) depending on waveband
  - Repeat: 2-day global repeat, 1-day or less poleward of 30°
  - Improvement over heritage (AVHRR)
## MODIS Land Bands

<table>
<thead>
<tr>
<th>Band number</th>
<th>Spatial resolution</th>
<th>Wavelength, nm</th>
<th>Waveband region</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250 m</td>
<td>620-670</td>
<td>Red</td>
</tr>
<tr>
<td>2</td>
<td>250 m</td>
<td>841-876</td>
<td>Near-infrared</td>
</tr>
<tr>
<td>3</td>
<td>500 m</td>
<td>459-479</td>
<td>Blue</td>
</tr>
<tr>
<td>4</td>
<td>500 m</td>
<td>545-565</td>
<td>Green</td>
</tr>
<tr>
<td>5</td>
<td>500 m</td>
<td>1230-1250</td>
<td>Near-infrared</td>
</tr>
<tr>
<td>6</td>
<td>500 m</td>
<td>1628-1652</td>
<td>Shortwave infrared</td>
</tr>
<tr>
<td>7</td>
<td>500 m</td>
<td>2105-2135</td>
<td>Shortwave infrared</td>
</tr>
</tbody>
</table>
Daily MODIS Coverage
True-color browse image
This MODIS image shows large parts of Oregon and Washington.

- Clouds
- Forest
- Smoke from a fire
- Arid areas
Monitoring Desertification and Land Reclamation in Egypt
Curtis E. Woodcock (and others)

Goals:

- Evaluation of the location and extend of desertification in the Nile Delta
- Mapping and monitoring the newly reclaimed lands of the Western Desert and coastal areas

What is our definition of desertification?

*Reduced fertility of agricultural soils due to waterlogging, salinization, urbanization, and being covered by windblown sand (did not occur in our study area)*
Conditions in Egypt

- Least amount of arable land per capita in the world
- Limited other natural resources
- Constant struggle to feed and improve the diet of a growing population
- Half the population participates in agriculture
- Aswan high dam is a mixed blessing
- Ministry of Agriculture is extremely important
- How many of you know who the Minister of Agriculture is in your country?
Outside the Nile Delta, the Western Desert is extremely arid and largely devoid of vegetation.
Normal, healthy fields in the delta. Notice that new housing is often built on top of existing houses, so often the top is left unfinished.
There are large extents in the Delta that have been abandon from agricultural production due to soil salinity problems.
Salt is plainly visible as a surface crust in many areas. (The plants are salicornia, common to salt marshes)
Our study area included a single Landsat scene that covers about 2/3 of the Nile Delta and much of the adjacent Western Desert.
TRADITIONAL IMAGE ANALYSIS DOES NOT ACCOUNT FOR AGRARIAN PRACTICES COMMON IN THE REGION.

- CONSTANT AVAILABILITY OF IRRIGATION WATER AND MILD CLIMATE PERMIT FIELDS TO SUPPORT MULTIPLE CROPS IN ONE YEAR
- FLEXIBILITY IN THE AGRICULTURAL GROWING CYCLES
- SPECTRAL CONFUSION BETWEEN TEMPORARILY FALLOW FIELDS AND UNPRODUCTIVE, BARREN LANDS
- AVERAGE FARM SIZE IS LESS THAN 2.5 ACRES

NEW METHODS ARE NEEDED TO MONITOR THE AGRICULTURAL LANDS OF EGYPT.

METHODS BASED ON MULTITEMPORAL PATTERNS OF NDVI
NDVI: based on the dramatic difference in reflectance between the NIR and red wavelengths for vegetation.

\[
NDVI = \frac{IR - Red}{IR + Red} = \frac{TM\,4 - TM\,3}{TM\,4 + TM\,3}
\]
The variability in planting times for individual fields will result in some healthy, productive fields having low NDVI values in some images.
Conceptual model for the behavior of different land covers.
Strategy: Use the Max and Range of NDVI from many images to find areas chronically unproductive.
9 Landsat TM images - Ranging over 9 years

Western Nile Delta  Landsat TM Imagery 1984–1993
• Preprocessing:
  Geometric Registration
  Radiometric Matching
  Calculation of NDVI

Notice the drop in variability for stable surface features following image “matching”. Stable dark (ocean) and bright (desert) sites were used to correct each band to match the June 92 image.
Soil Salinity measurements as a surrogate for fertility

- Field Data Collection Procedures
  - Locate site on the TM image
  - Collect soil samples for lab analysis of salinity levels
  - Take photographs of the site
  - Soil and Water Research Institute from Giza
Results used to calibrate our Max and Range NDVI relationship

Maximum NDVI vs Range NDVI by Salinity Level

- low-moderate
- moderate-high
- high-extreme
- extreme
Monitoring Reclamation

- Sites outside the Delta were identified as reclaimed any time NDVI surpassed a threshold.
- Areas of urban growth (urbanization) was separated from the “reduced productivity” class by use of the spatial proximity to existing urban areas. (It was interesting to find that spectrally, urban areas in the Nile Delta can not be separated from fallow fields or areas of reduced productivity!)
The whole map!  
It is hard to see much detail at this scale! 

(We’ll look at the circled areas more closely)
There are extensive salinity problems near Lake Burullus. Note the expansion of agriculture onto the beach areas along the Mediterranean.
There is both significant expansion of agriculture, and significant loss of agricultural land along the western edge of the Nile Delta.
This time series shows great expansion of agriculture southwest of Alexandria. This image is from 1986.
Final Map: colors are the different years of reclamation
Maps are untested hypotheses without accuracy assessment!

### ACCURACY ASSESSMENT

<table>
<thead>
<tr>
<th>Map Label</th>
<th>Sites</th>
<th>urban</th>
<th>urbaniz</th>
<th>red. prod.</th>
<th>agric. delta</th>
<th>agric. desert</th>
<th>reclaim</th>
<th>wet. reclaim</th>
<th>other</th>
<th>user’s accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>urban</td>
<td>28</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
</tr>
<tr>
<td>urbanization</td>
<td>17</td>
<td>4</td>
<td>8</td>
<td>1</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>47.06%</td>
</tr>
<tr>
<td>reduced productivity</td>
<td>31</td>
<td>5.5*</td>
<td>2.5*</td>
<td>19</td>
<td>3</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>61.29%</td>
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<tr>
<td>agriculture in delta</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75</td>
<td></td>
<td></td>
<td>100.00%</td>
</tr>
<tr>
<td>agriculture in desert</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td></td>
<td>1</td>
<td>1</td>
<td>84.62%</td>
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<tr>
<td>reclamation</td>
<td>27</td>
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<td></td>
<td>6</td>
<td>18</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>66.67%</td>
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<td>wetlands reclaimed</td>
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<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>1</td>
<td></td>
<td>75.00%</td>
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<tr>
<td>other</td>
<td>70</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70</td>
<td>100.00%</td>
</tr>
<tr>
<td><strong>totals</strong></td>
<td>265</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>87.55%</td>
</tr>
</tbody>
</table>

Confusion matrix for user’s accuracy. * Mixed ground features at one site made it impossible to assign a single class label to the site. This site was divided between two classes.
Area estimates can be improved by using the information in the accuracy assessment!

### Changes in Areal Estimates of the Principle Map Classes as a Result of the Accuracy Assessment (in hectares)

<table>
<thead>
<tr>
<th>Map Class</th>
<th>Map Estimate</th>
<th>Adjusted Estimate</th>
<th>Change</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>69,033</td>
<td>82,061</td>
<td>13,028</td>
<td>18.87</td>
</tr>
<tr>
<td>Urbanization</td>
<td>6,575</td>
<td>8,313</td>
<td>1,738</td>
<td>26.43</td>
</tr>
<tr>
<td>Reduced productivity</td>
<td>64,711</td>
<td>40,048</td>
<td>-24,663</td>
<td>-38.11</td>
</tr>
<tr>
<td>Delta agriculture</td>
<td>1,023,732</td>
<td>1,031,541</td>
<td>7,810</td>
<td>0.76</td>
</tr>
<tr>
<td>Desert agriculture</td>
<td>110,346</td>
<td>121,467</td>
<td>11,121</td>
<td>10.08</td>
</tr>
<tr>
<td>Reclamation</td>
<td>126,437</td>
<td>92,780</td>
<td>-33,658</td>
<td>-26.62</td>
</tr>
</tbody>
</table>
CONCLUSIONS

MULTITEMPORAL SATELLITE REMOTE SENSING IS USEFUL IN MAPPING AND MONITORING THE STATUS OF AGRICULTURAL LANDS IN EGYPT.

FIELDS OF REDUCED AGRICULTURAL PRODUCTIVITY CAN BE SEPARATED SUCCESSFULLY FROM FIELDS OF NORMAL PRODUCTIVITY IN THE NILE DELTA USING MULTITEMPORAL NDVI FEATURES.

IN THE NILE DELTA

AS OF APRIL 1993, 3.74% OF AGRICULTURAL LANDS HAVE SIGNIFICANTLY REDUCED AGRICULTURAL PRODUCTIVITY. THE EXTENT OF THESE REDUCED PRODUCTIVITY LANDS IS GREATER THAN ANTICIPATED, INDICATING A NEED TO INCORPORATE THESE LANDS IN RECLAMATION PLANNING.


IN THE WESTERN DESERT AND COASTAL AREAS, 43.3% OF CULTIVATED LANDS IN 1993 HAD BEEN RECLAIMED AND PUT INTO PRODUCTION AFTER 1985.

MAP ACCURACY ASSESSMENT IS CRITICAL TO AREAL ESTIMATES.
Modeling and Forecasting Effects of Land-Use Change in China Based on Socioeconomic Drivers

Boston University
Department of Geography
Robert Kaufmann
Curtis E. Woodcock
Dennis G. Dye
Karen C. Seto (her PhD!)

Chinese Collaborators:    Lu Jinfà, Institute of Geography CAS
                        Li Xiaowen, IRSA
                        Wang Tongsan, Economic Forecasting Center
                        Huang Xiuhua, IRSA
                        Liang Youcai, State Information Center

Global Rates of Urbanization

- >50% of world population
- 30% urban in 1950, estimated 60% urban in 2030
- 19 megacities > 10 million
- 22 cities with 5 to 10 million
- 370 cities with 1 to 5 million
- 440 cities with 0.5 to 1 million
- Highest growth rates in medium-sized cities (1-5 million)
<table>
<thead>
<tr>
<th>Cities as problems</th>
<th>Cities as solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Unemployment</td>
<td>● Driving forces in economic growth</td>
</tr>
<tr>
<td>● Environmental degradation</td>
<td>● Efficient use of infrastructure</td>
</tr>
<tr>
<td>● Loss of agricultural land</td>
<td>● Delivery of health services</td>
</tr>
<tr>
<td>● Pressure on natural resources (energy, water, land)</td>
<td>● Sanitation</td>
</tr>
<tr>
<td>● Deficiencies in urban services</td>
<td>● Education</td>
</tr>
<tr>
<td>● Deterioration of infrastructure</td>
<td>● “Saving land for nature”</td>
</tr>
<tr>
<td>● Inadequate housing</td>
<td>● Efficient natural resource use</td>
</tr>
<tr>
<td>● Consumption patterns</td>
<td></td>
</tr>
</tbody>
</table>
Urbanization trends in China

• One quarter of world's 500 largest urban areas in China
• 2050: China’s urban population increase by 300-700 mil.
• 2002 urbanization rate: 36%
• 2050 urbanization rate: 70%
• US (2000): 77%
• Japan (2000): 79%
• Germany (2000): 88%
Migration and urbanization trends in China, 2000

- Highest interprovincial in-migration: Guangdong (14.43%)
- Highest interprovincial out-migration: Jiangxi (7.12%)
- Lowest interprovincial in-migration: Henan (0.54%)
- Lowest interprovincial out-migration: Guangdong (0.55%)

Motivations for Land-Use Change Research in China

Rapid economic development

- 1978-1996 annual GDP growth: 9 -13%
- Raised per capita income
- Changed dietary standards

Implications for land use

- Massive migrations
- Rapid urbanization
- Grain-based to meat-based diets
Why Pearl River Delta, Guangdong Province?

- Major agricultural region and national leader in production of:
  - lychees, bananas, pond fish, sugar cane
- Special Economic Zones
- Geographic proximity to Hong Kong
- Cultural ties to overseas Chinese investors
Pearl River Delta, China

- Major agricultural region
- Special Economic Zones
- Geographic proximity to Hong Kong
- Cultural ties to overseas Chinese investors
- 33-48 million
Study Area: Pearl River Delta

Landsat TM 432 (RGB) 12.30.95
Is this really China???
Typical new housing being built throughout the PRD
Typical urban dwellings (Guong Zhou)
Buildings of several stories are being built with bamboo scaffolding and without the use of cranes! Huge amounts of manual labor!
The local hills have been mined as a source of building materials!
Notice the bamboo scaffolding!
<table>
<thead>
<tr>
<th>Land-Use/Cover Class</th>
<th>Stable or Change to Land-Use/Cover Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Water → Fish pond</td>
</tr>
<tr>
<td></td>
<td>Water → Agriculture</td>
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<tr>
<td></td>
<td>Water → Transition</td>
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<td></td>
<td>Water → Urban</td>
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<tr>
<td>Forest</td>
<td>Forest → Water</td>
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<td>Forest → Transition</td>
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<td>Forest → Urban</td>
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<tr>
<td>Shrub</td>
<td>Shrub → Water</td>
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<td></td>
<td>Shrub → Transition</td>
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<td></td>
<td>Shrub → Urban</td>
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<td>Fish Pond</td>
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</tr>
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<td>Agriculture</td>
<td>Agriculture → Water</td>
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<tr>
<td>Urban</td>
<td></td>
</tr>
</tbody>
</table>
Land-Use Change Map

10 December 1988 TM 432

3 March 1996 TM 432

- water
- natural vegetation
- agriculture
- urban
- natural to urban
- agriculture to urban

5 km
Land-Use Change Map

- 10 December 1988 TM 432
- 3 March 1996 TM 432

Legend:
- Water
- Natural vegetation
- Agriculture
- Urban
- Agriculture to water
- Natural to urban
- Agriculture to urban

Scale: 5 km
Contributions of Research

• Successful mapping of land-use change with high accuracy (93.5%)

• Amount of developed land has increased by 319% between 1988 and 1996

• Developed new method to evaluate change in series of images using time series techniques

• Identified and quantified major drivers of urbanization
MONITORING CHANGES IN IRRIGATED LANDS IN SOUTHEASTERN TURKEY WITH MODIS AND LANDSAT

Mutlu Ozdogan, Curtis E. Woodcock, and Guido D. Salvucci

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Situation in SE Turkey

- Large-scale water resources development project in SE Turkey known as the GAP (Turkish acronym for Southeastern Anatolia Project).
- 22 dams within the Euphrates-Tigris Basin with irrigation network planned to serve 1.7 million hectares by 2010.
- Currently ~300,000 hectares of land is being irrigated.
Agricultural Water Use

![Graph showing the assessment and forecast of population, irrigated land area, and specific irrigation over years from 1950 to 2030.](image-url)
Multidisciplinary Research Project

- To assess the hydro-climatological impact of large-scale irrigation.
  - Remote sensing estimates of irrigated acreage for 10 years
  - Evapotranspiration estimates based on Penman-type approach
  - Meso-scale climate modeling to understand future impacts

http://www.bu.edu/remotesensing/Research/Turkey/index.html
Atatürk Dam and Reservoir

1975

1999
ETM+ image
September 1, 1999
IKONOS image
December, 2000
Harran Plain

1978 1992 1999

All late-summer images
Results (Remote Sensing of Irrigation)

- Between 1980 and 2002 irrigated area has increased ~2000 percent
- Similar increase in agricultural water use
- 1.18 bcm in 2002 (~3% of total Euphrates flow)
- MODIS data useful for optimum timing
- NDVI thresholding method is reliable
- Applicable in other areas with single crop
Implications for the hydrologic cycle

- Main Question:
  - What is the impact of increased irrigation on the hydrological cycle and climate?

- Concentrating on Evapotranspiration
  - Simple models suited for changing moisture
  - Use routine meteorological observations
  - Capable of representing feedbacks between land surface and atmosphere
Complementary Relationship (CR)

- Based on heuristic arguments of Bouchet (1963)
- Simply states that the *potential* and *actual* evapotranspiration are not independent, but form a complementary relationship
Evaporation Definitions

- **Actual evaporation** ($E_a$) is defined as the actual amount of water leaving earth’s surface in the form of atmospheric water vapor.
- **Potential evaporation** ($E_p$) is defined as the amount of evaporation that would occur, if unlimited water source were available. An upper limit to actual evaporation, atmosphere limited.
- **Equilibrium evaporation** ($E_w$) is defined as potential evaporation under minimum advection conditions. It represents a lower limit evaporation from moist surfaces (it is rarely achieved).
- 23 year record
- daily data
- Temperature, vapor pressure, solar radiation, wind speed
Summer (90-day) means
CR Results (neutral case)

- $E_p$ decreased $\sim 15$ mm/day to $\sim 7$ mm/day
- Decrease in wind speed - primary cause
- CR holds for the study site - means:
  - Economies of scale exist!
  - Method for estimating ET
- $E_a$ increased 0 to $\sim 5$ mm/day
- Comparison against $E_a$ calculated from water balance shows good agreement
What can remote sensing tell us?

- Provides a means for studying the way our planet is changing, and in particular, how human activities are changing the planet
- We have just begun to scratch the surface of utilizing existing datasets to learn about how Earth is changing
Remote Sensing and Your Students!

- Who uses remote sensing (Earth Observations)
- Career paths
  - Science (diverse backgrounds)
    - Geography
    - Forestry and agriculture
    - Earth sciences (geology)
    - Atmospheric sciences
    - Biology (ecology)
    - Math and statistics, computer science, engineering and physics
  - IT perspective – tools, image processing, geographic information systems, GPS (mostly commercial)
  - Resource management (commercial, governmental and NGO)
    - Forestry, agriculture, mineral exploration, urban and regional planning, weather and climate, fisheries, land management agencies (wildlife, biodiversity …)
  - Satellites and Sensors (design, build, launch, operate) aerospace industry and government
  - Data systems – collect, process, archive, and distribute imagery