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

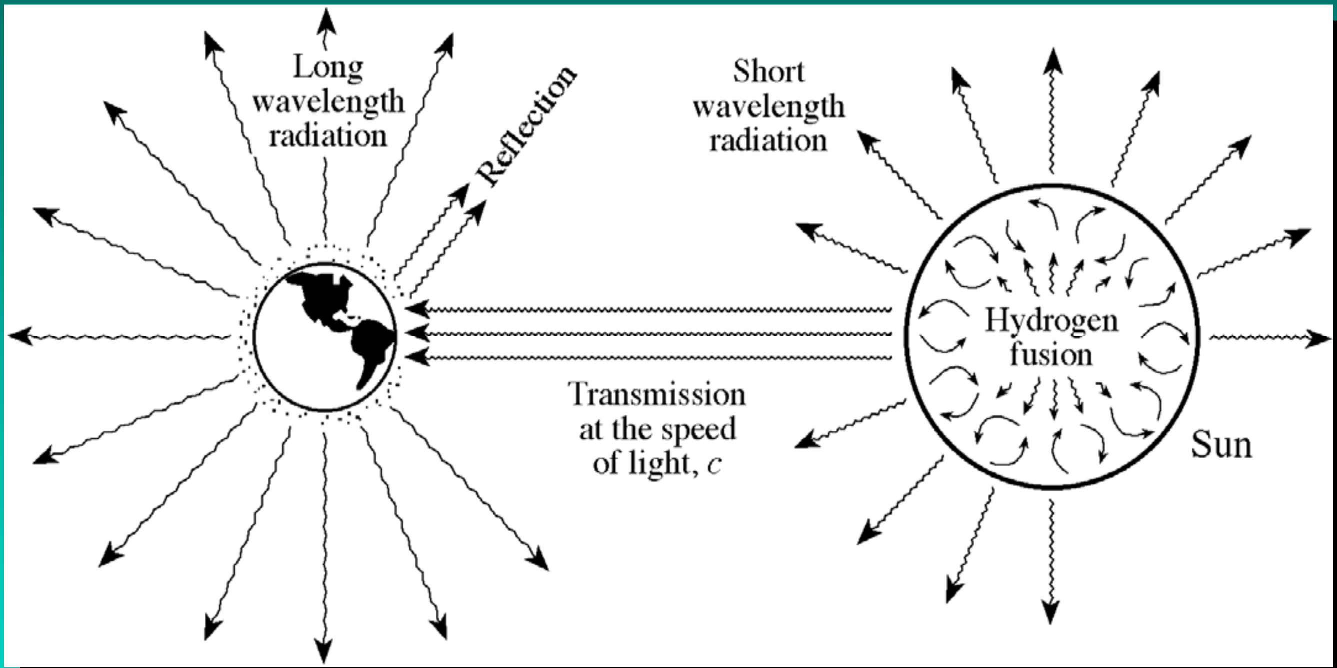
Prior projects

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

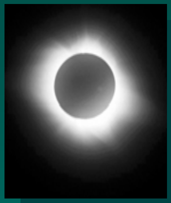
Professional Information

- Who uses remote sensing?
- What kinds of people comprise the remote sensing community?

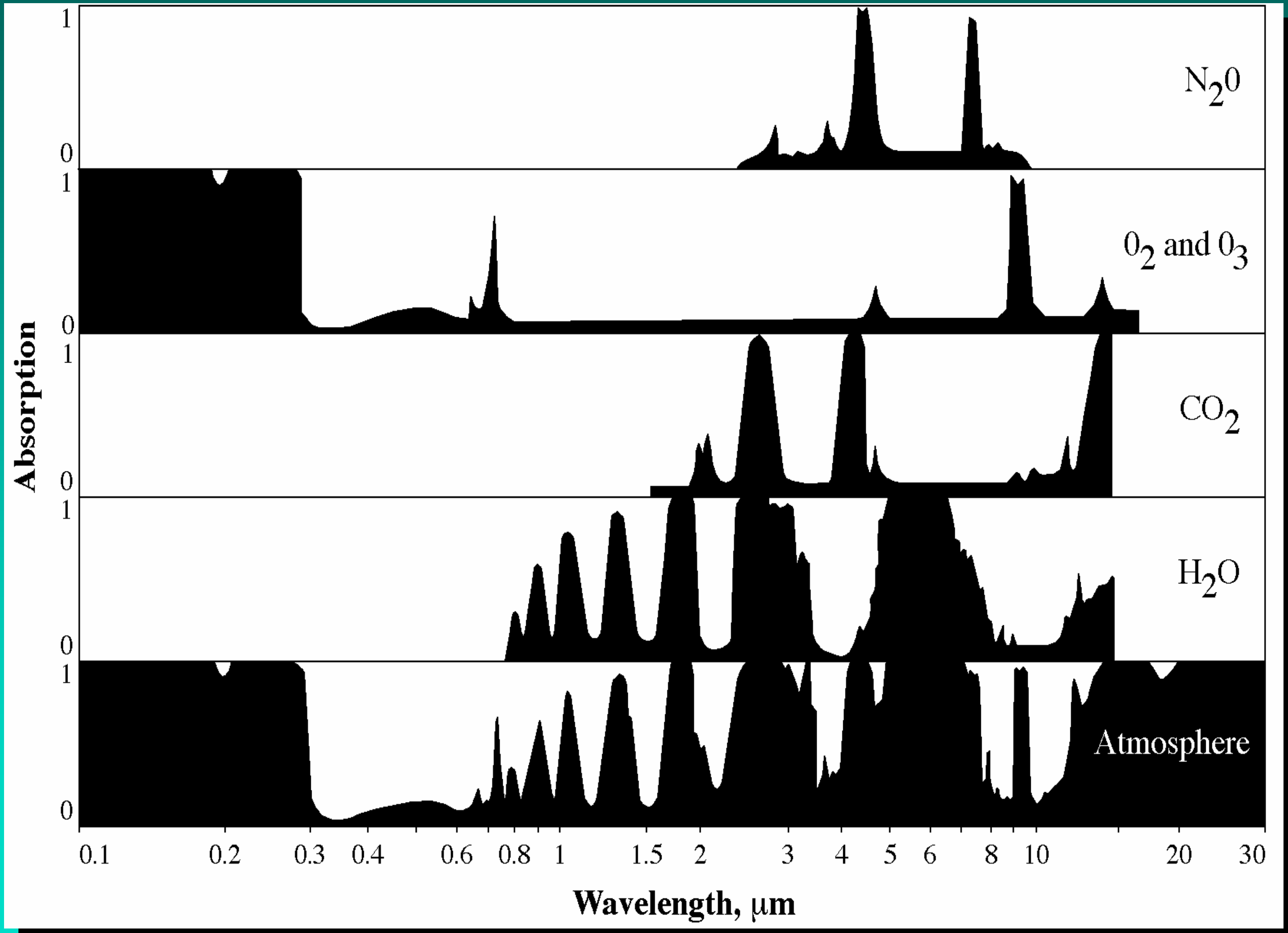
Sources of Electromagnetic Energy



"Optical Remote Sensing" uses measurements of reflected solar radiation

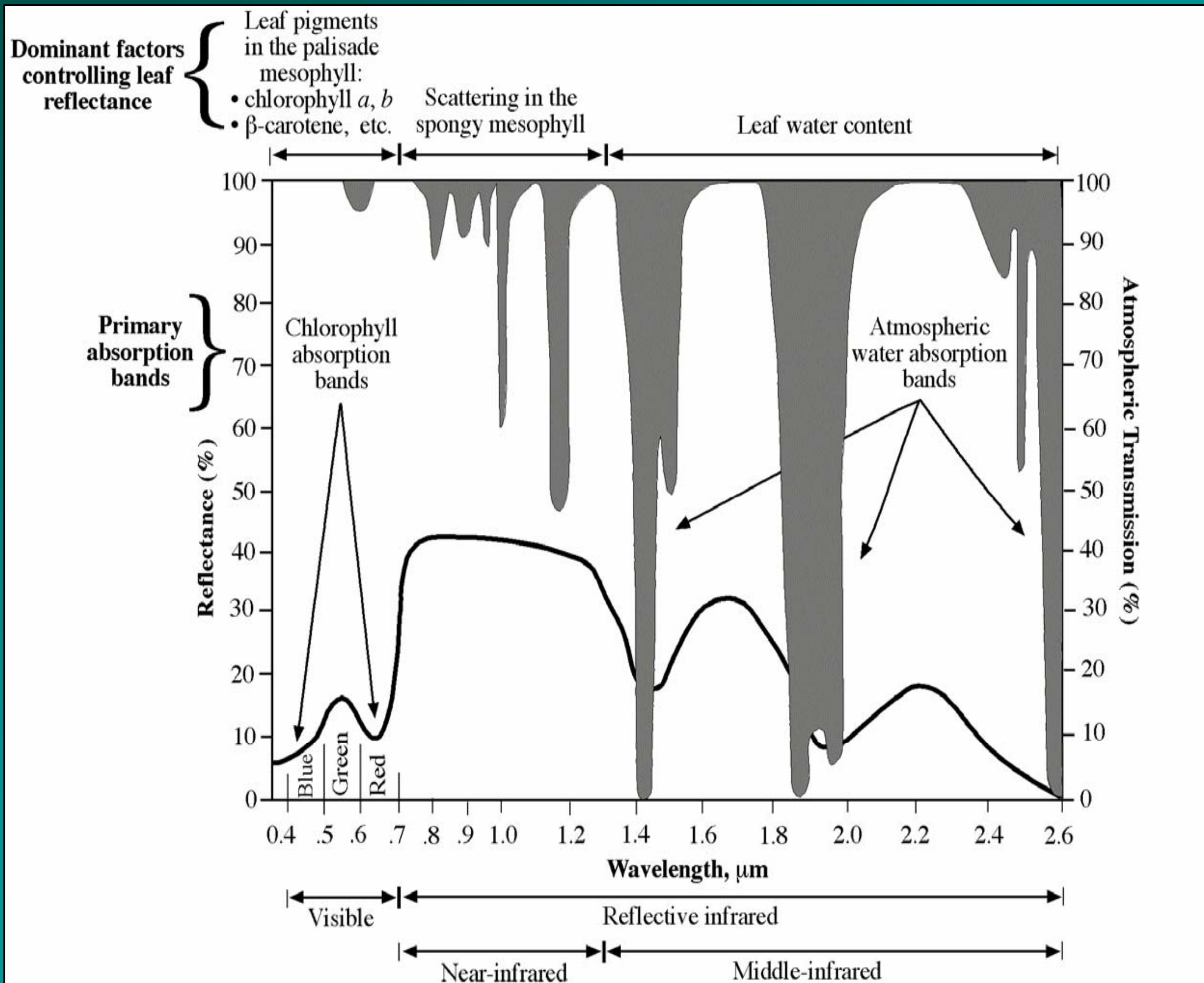


Absorption of the Sun's Incident Electromagnetic Energy in the Region from 0.1 to 30 μm by Various Atmospheric Gases



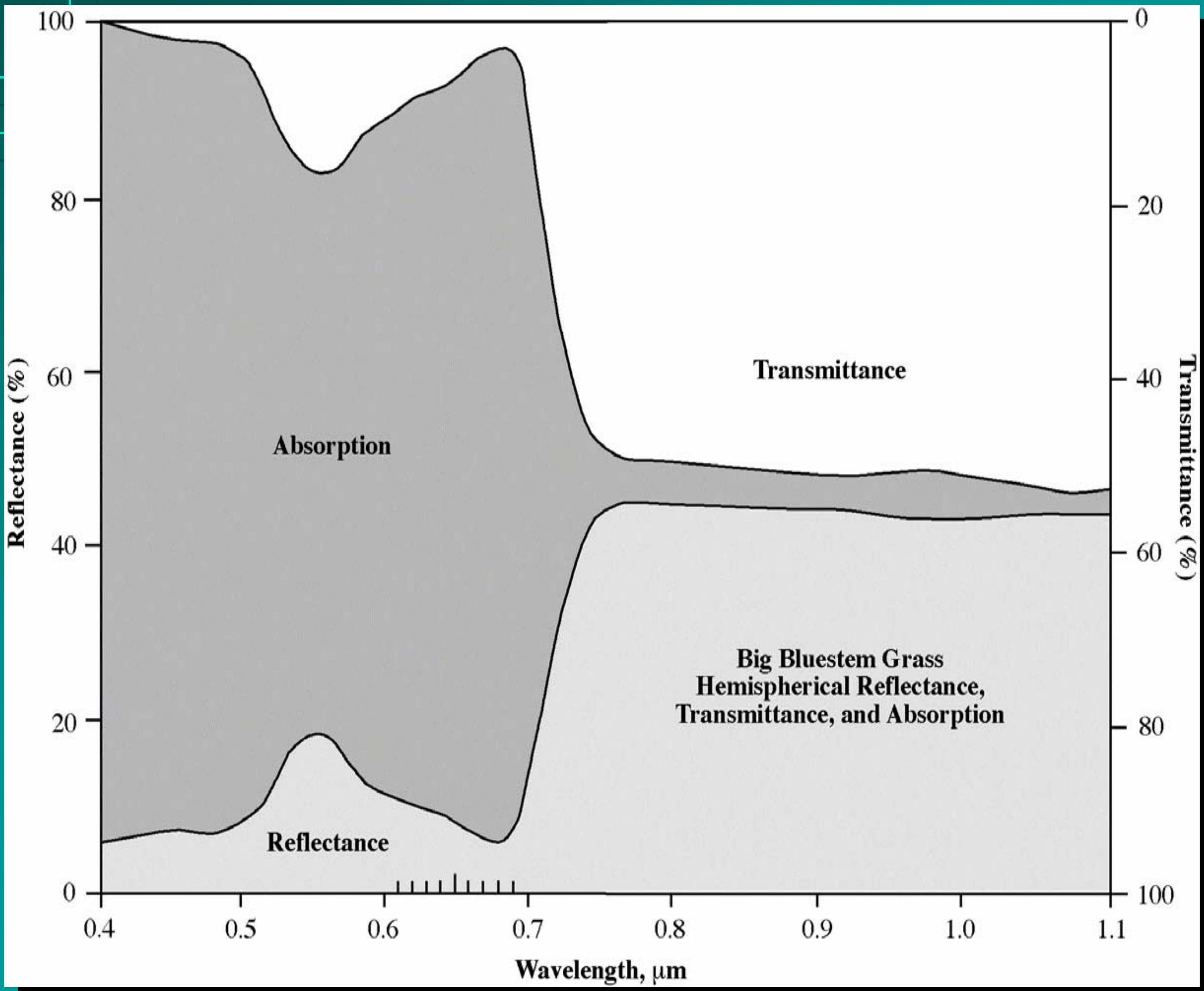
Jensen, 2000

Dominant Factors Controlling Leaf Reflectance

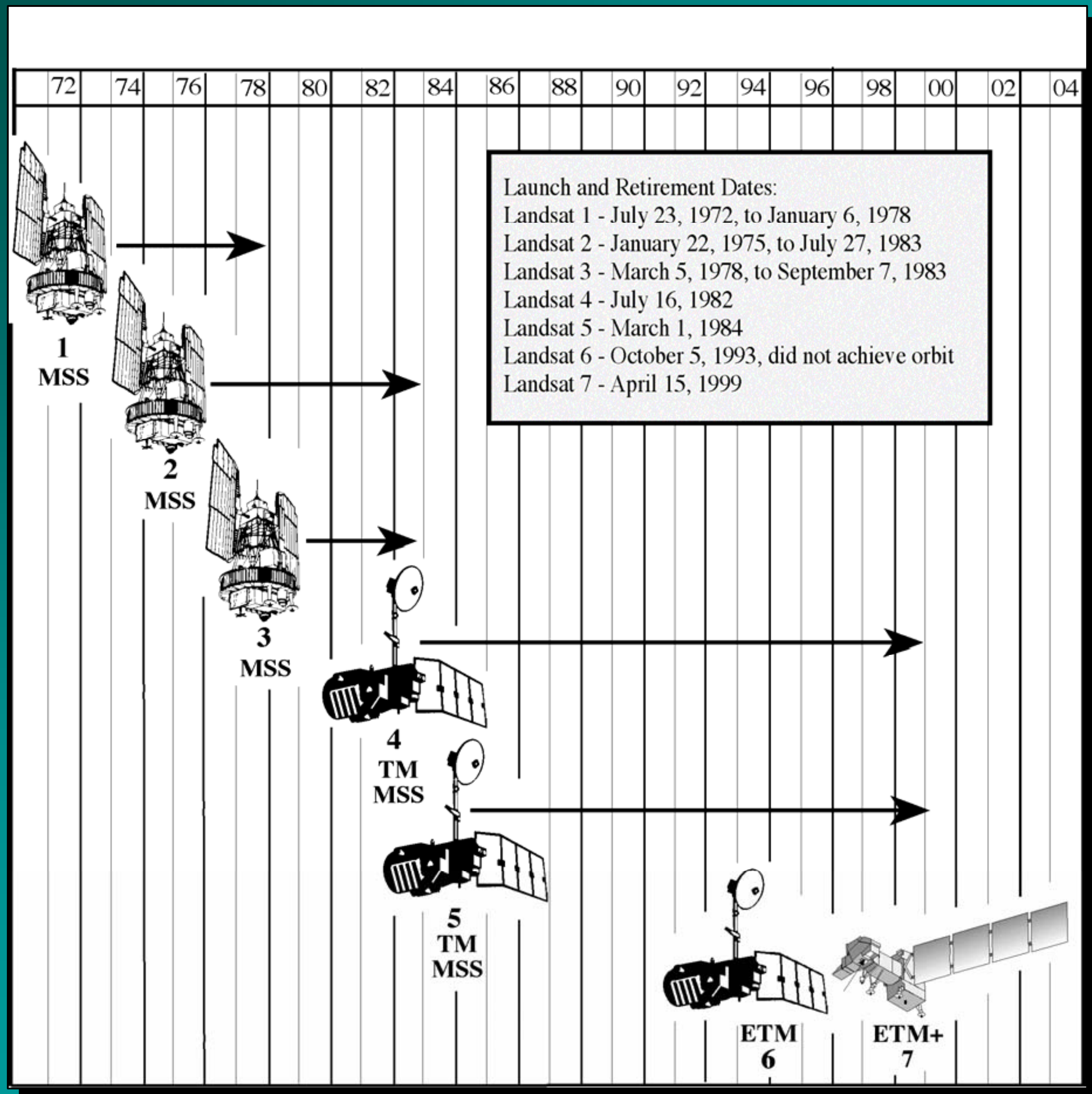


Water absorption bands:
0.97 μm
1.19 μm
1.45 μm
1.94 μm
2.70 μm

Hemispherical Reflectance, transmittance, and Absorption Characteristics of Big Bluestem Grass



Chronological Launch and Retirement History of the Landsat Satellite Series



Launch of Landsat 7 on April 15, 1999 from Vandenberg Air Force Base in California (on a Delta rocket)

Landsat Sensor Characteristics

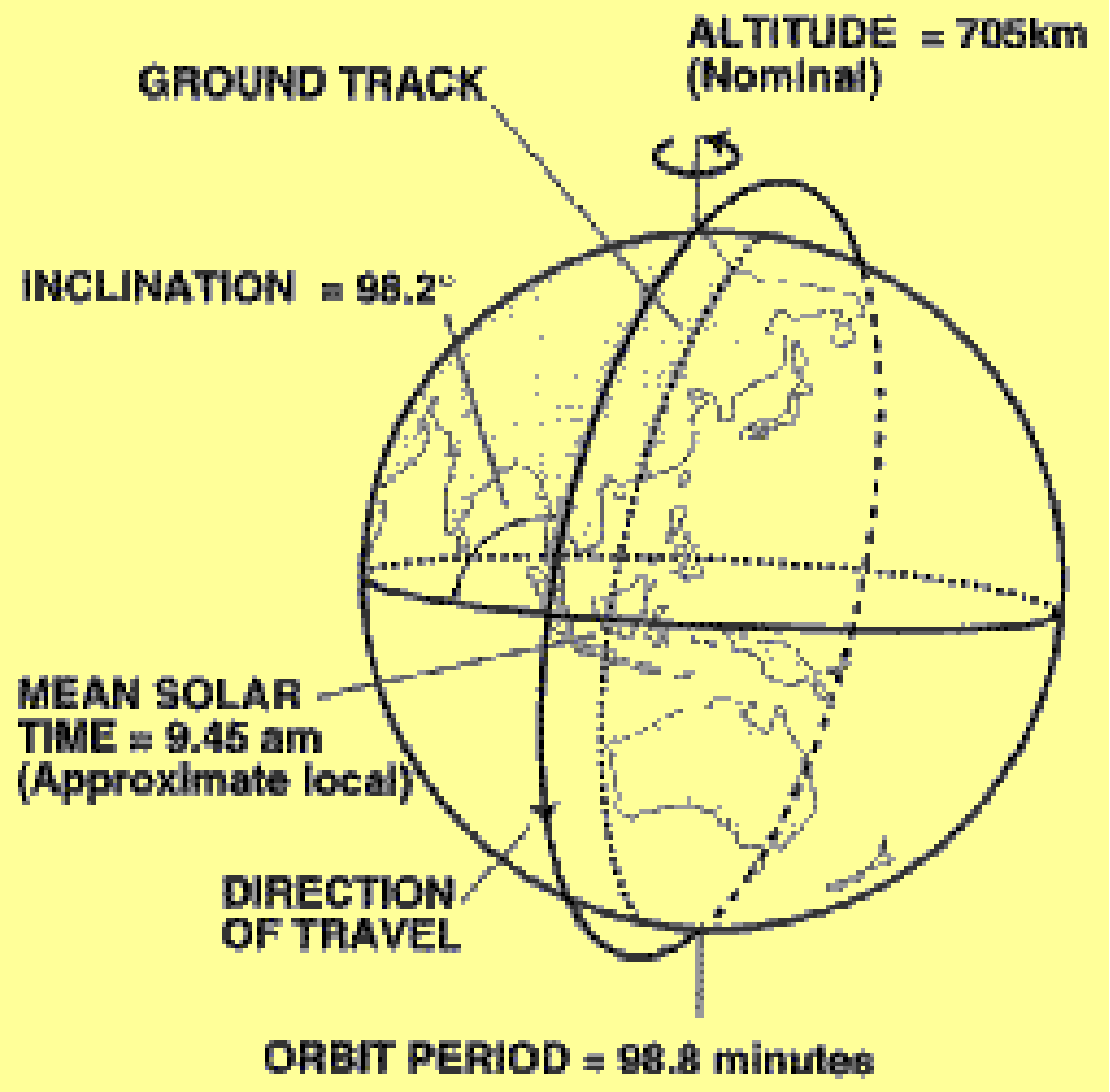
(Note in particular Landsat TM and ETM+)

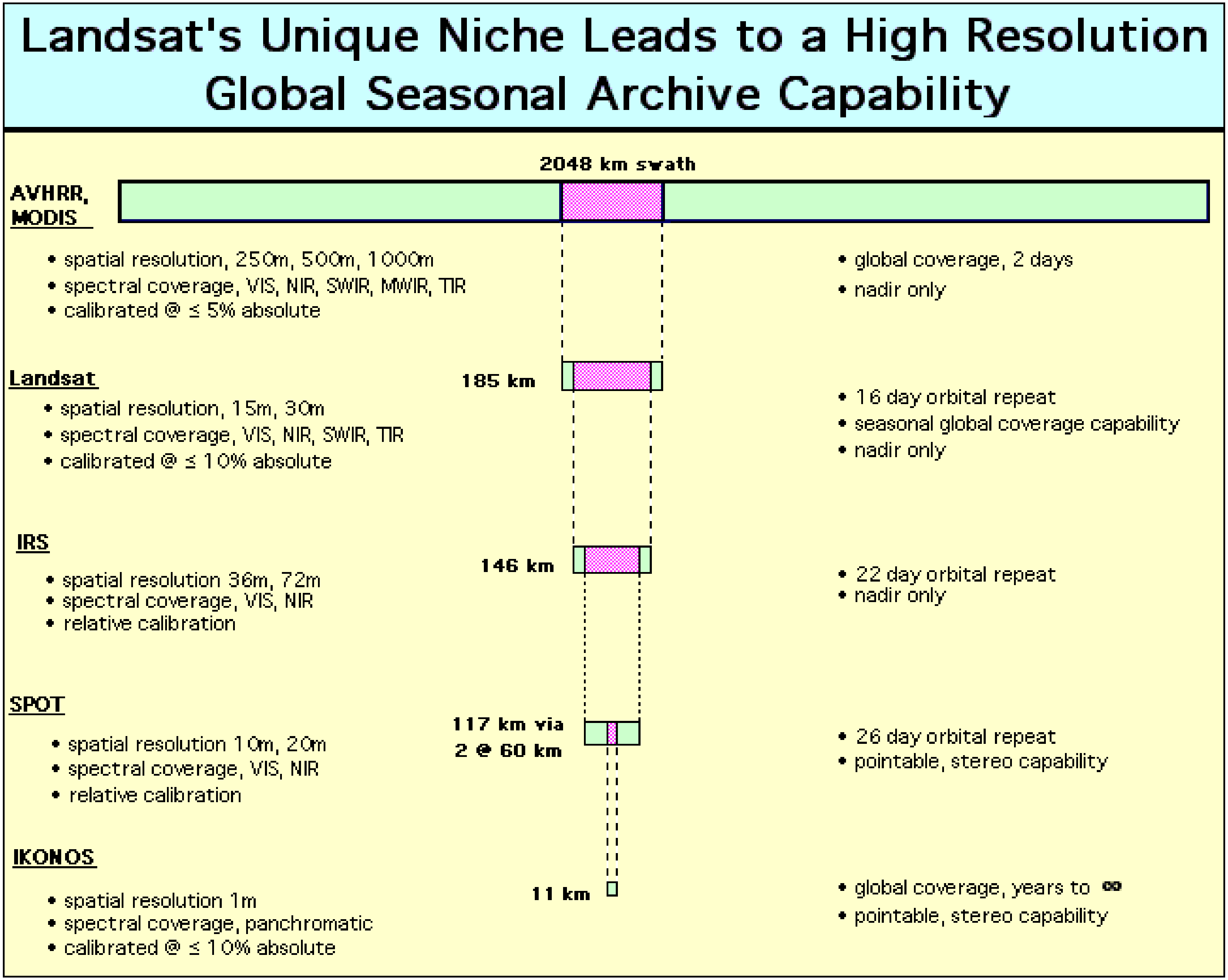
Satellite	Sensor	Bandwidths	Resolution
LANDSATs 1-2	RBV	(1) 0.48 to 0.57	80
		(2) 0.58 to 0.68	80
		(3) 0.70 to 0.83	80
	MSS	(4) 0.5 to 0.6	79
		(5) 0.6 to 0.7	79
		(6) 0.7 to 0.8	79
		(7) 0.8 to 1.1	79
LANDSAT 3	RBV	(1) 0.505 to 0.75	40
	MSS	(4) 0.5 to 0.6	79
		(5) 0.6 to 0.7	79
		(6) 0.7 to 0.8	79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

Satellite	Sensor	Bandwidths	Resolution
LANDSATs 4-5	MSS	(4) 0.5 to 0.6	82
		(5) 0.6 to 0.7	82
		(6) 0.7 to 0.8	82
		(7) 0.8 to 1.1	82
	TM	(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	120
		(7) 2.08 to 2.35	30
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

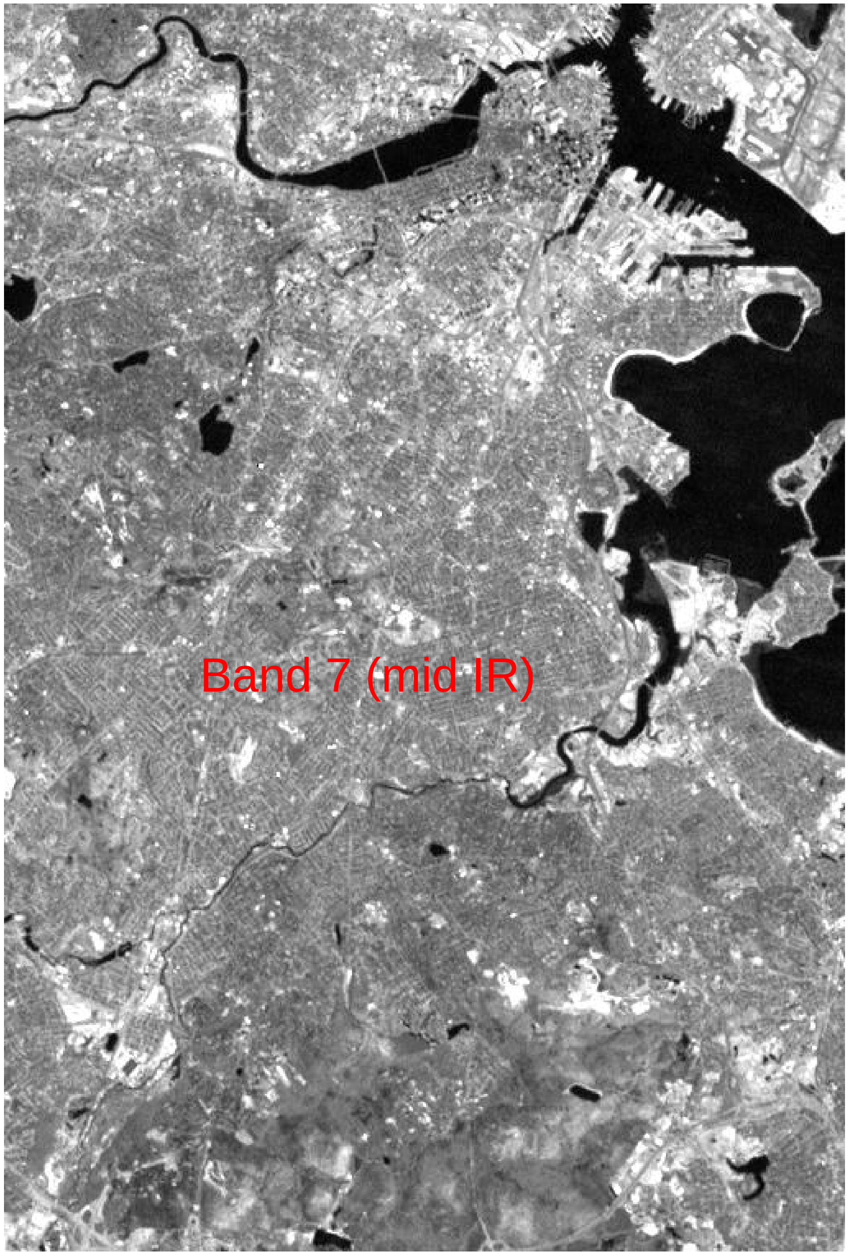
Important!

“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

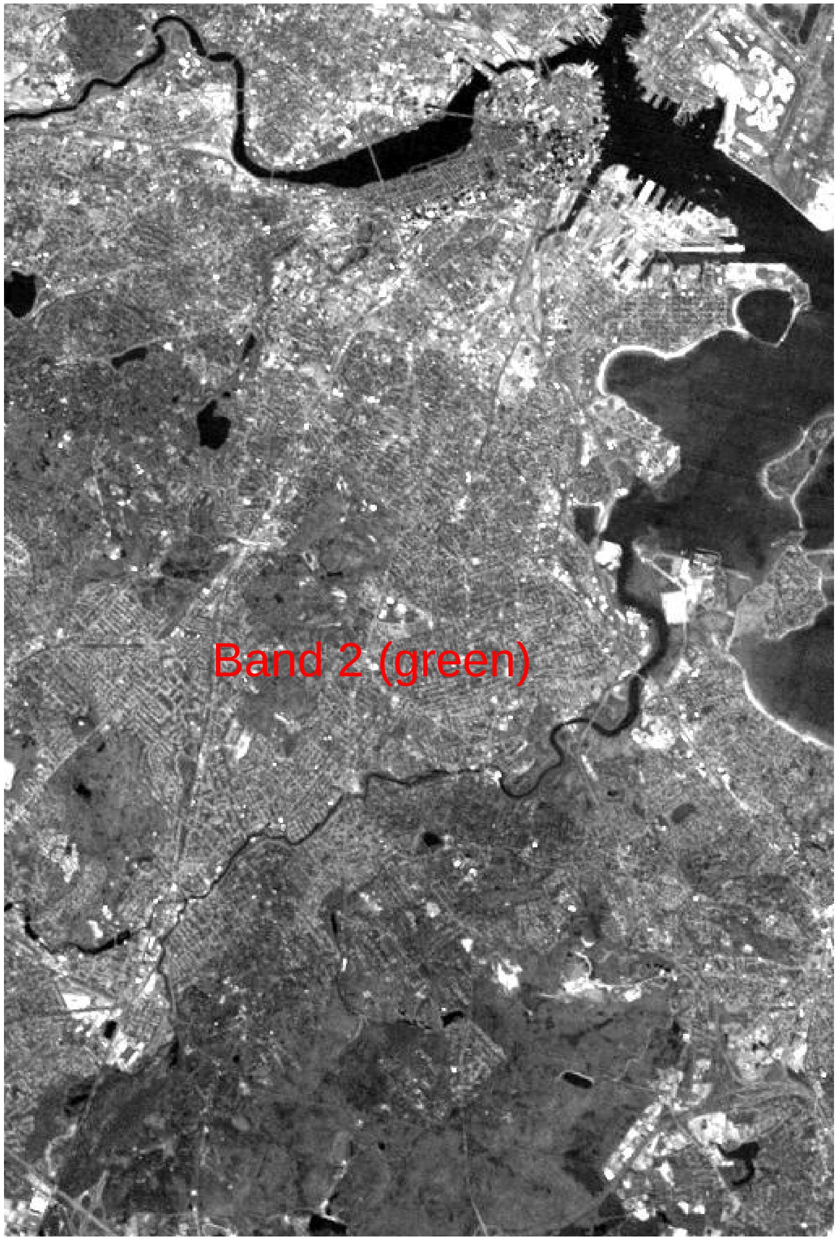


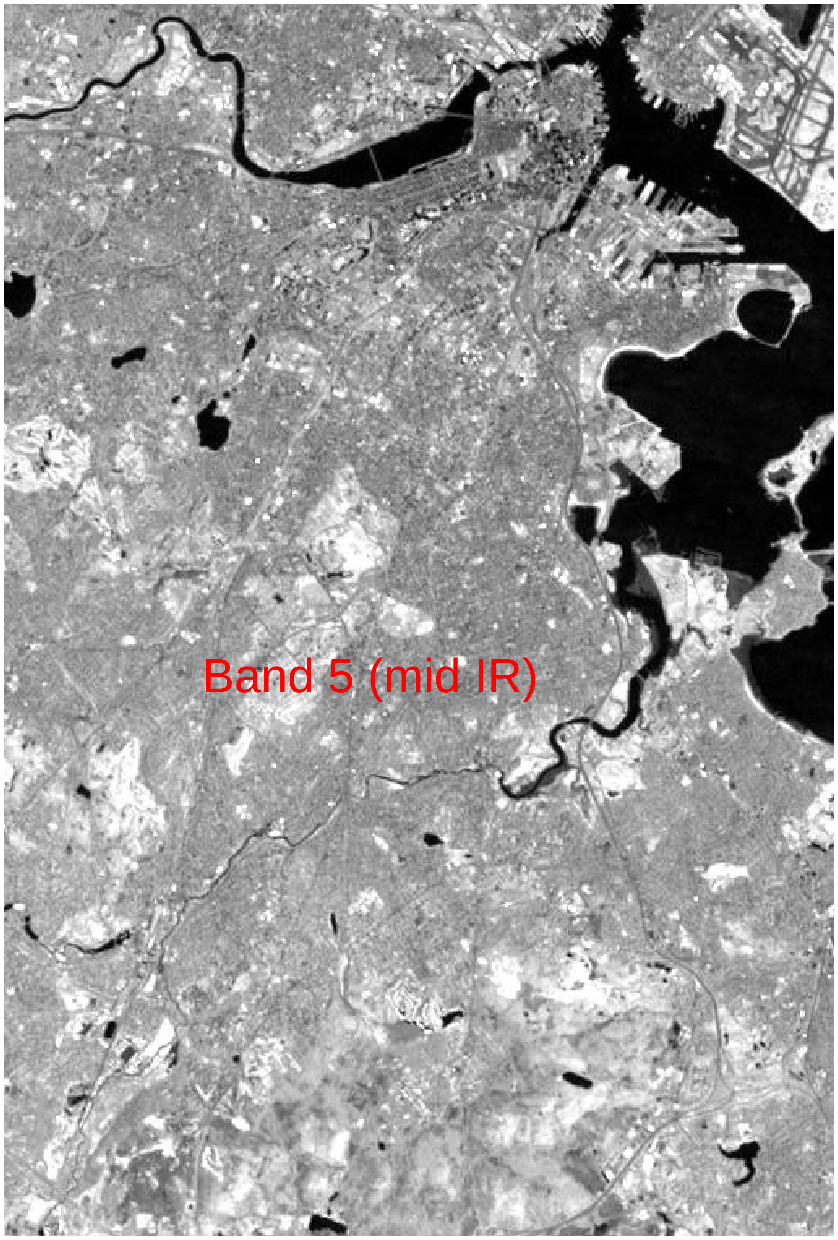

Landsat's Unique Niche Leads to a High Resolution Global Seasonal Archive Capability
2048 km swath
AVHRR, MODIS
• spatial resolution, 250m, 500m, 1000m
• spectral coverage, VIS, NIR, SWIR, MWIR, TIR
• calibrated @ ≤ 5% absolute
• global coverage, 2 days
• nadir only
Landsat
185 km
• spatial resolution, 15m, 30m
• spectral coverage, VIS, NIR, SWIR, TIR
• calibrated @ ≤ 10% absolute
• 16 day orbital repeat
• seasonal global coverage capability
• nadir only
IRS
146 km
• spatial resolution 36m, 72m
• spectral coverage, VIS, NIR
• relative calibration
• 22 day orbital repeat
• nadir only
SPOT
117 km via 2 @ 60 km
• spatial resolution 10m, 20m
• spectral coverage, VIS, NIR
• relative calibration
• 26 day orbital repeat
• pointable, stereo capability
IKONOS
11 km
• spatial resolution 1m
• spectral coverage, panchromatic
• calibrated @ ≤ 10% absolute
• global coverage, years to ∞
• pointable, stereo capability

Landsat Thematic Mapper Spectral Bands

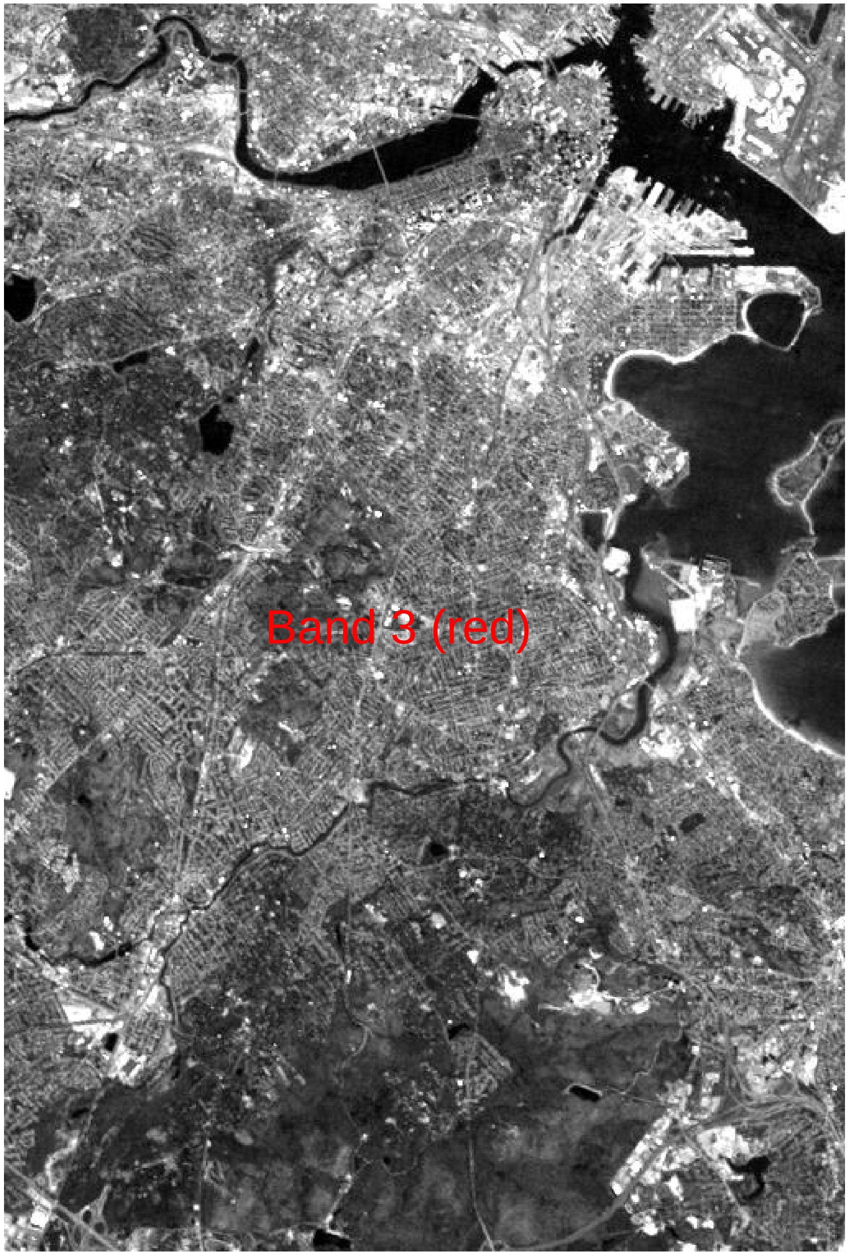


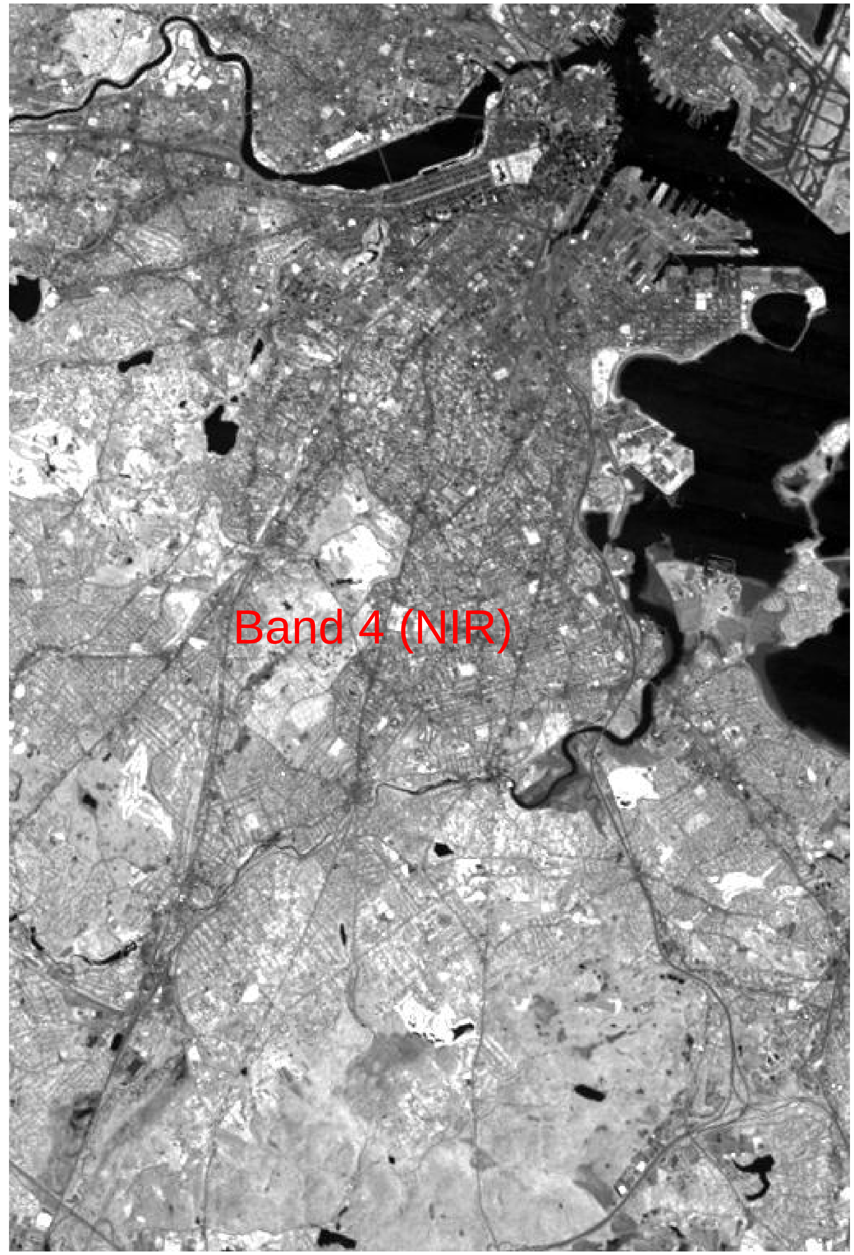
Landsat Thematic Mapper Spectral Bands



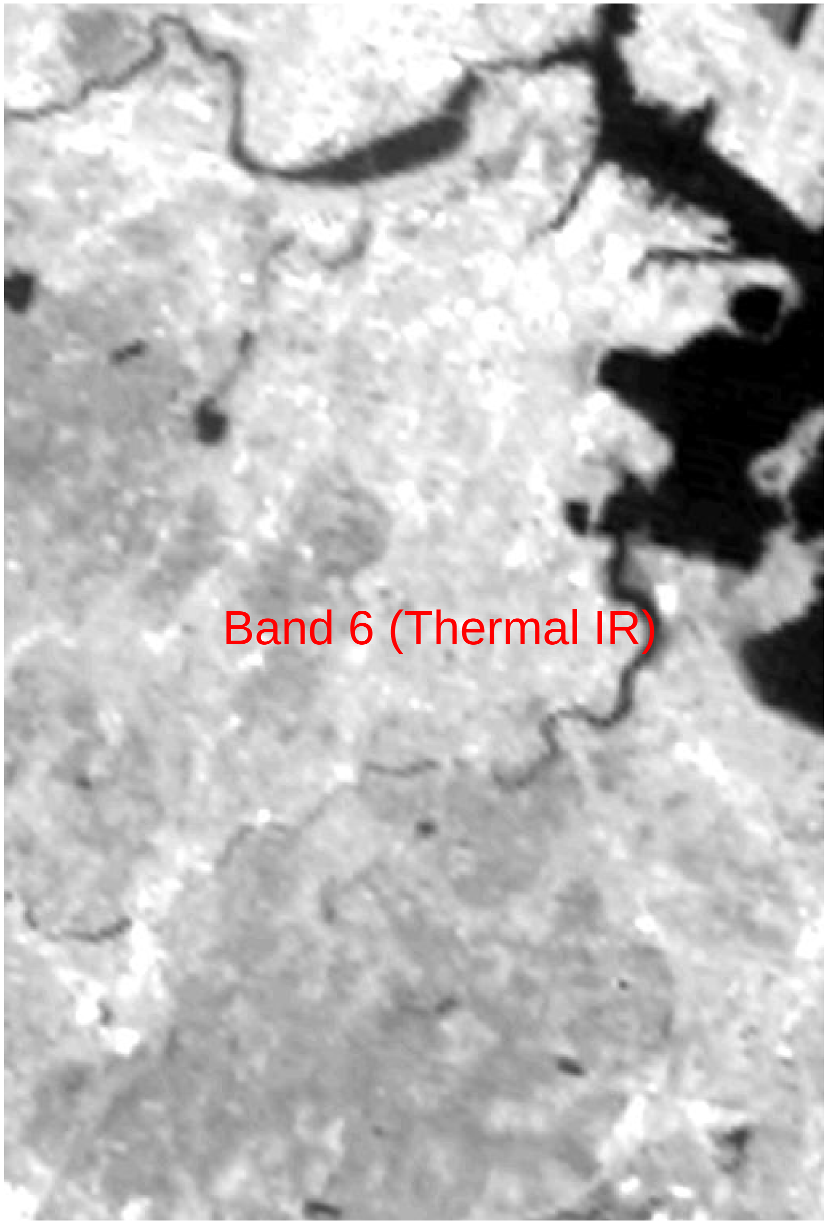


Landsat Thematic Mapper Spectral Bands





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!

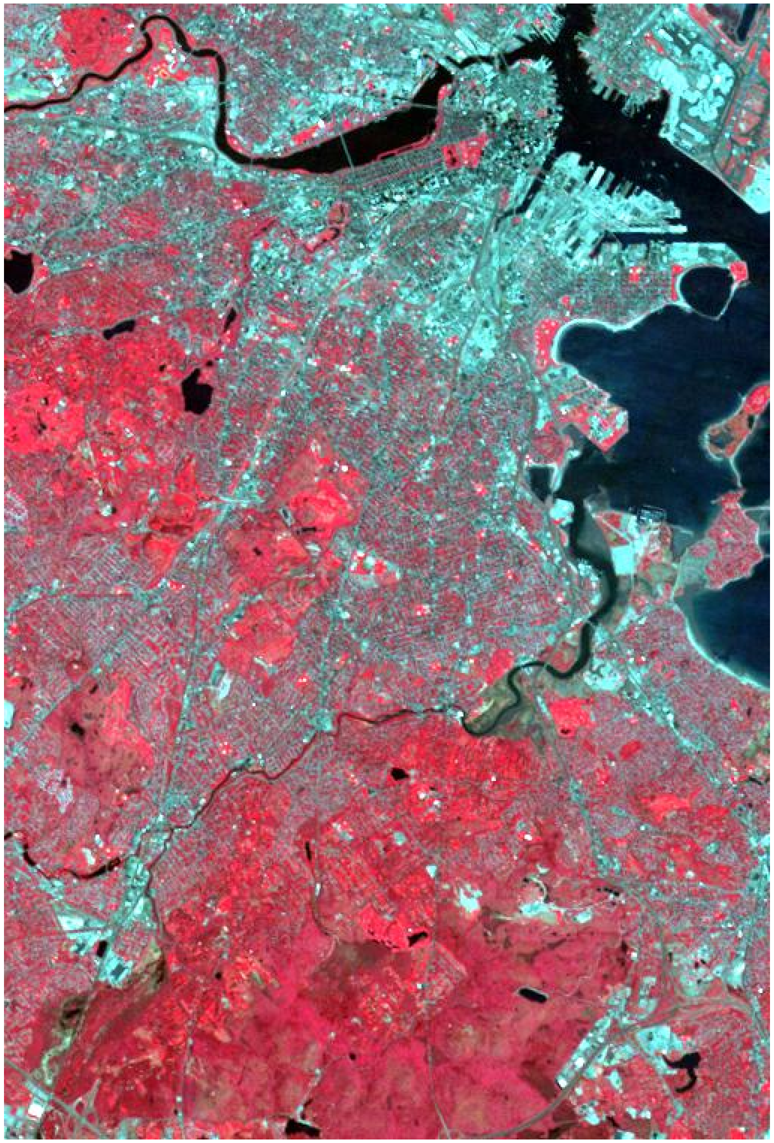
Landsat 321

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)



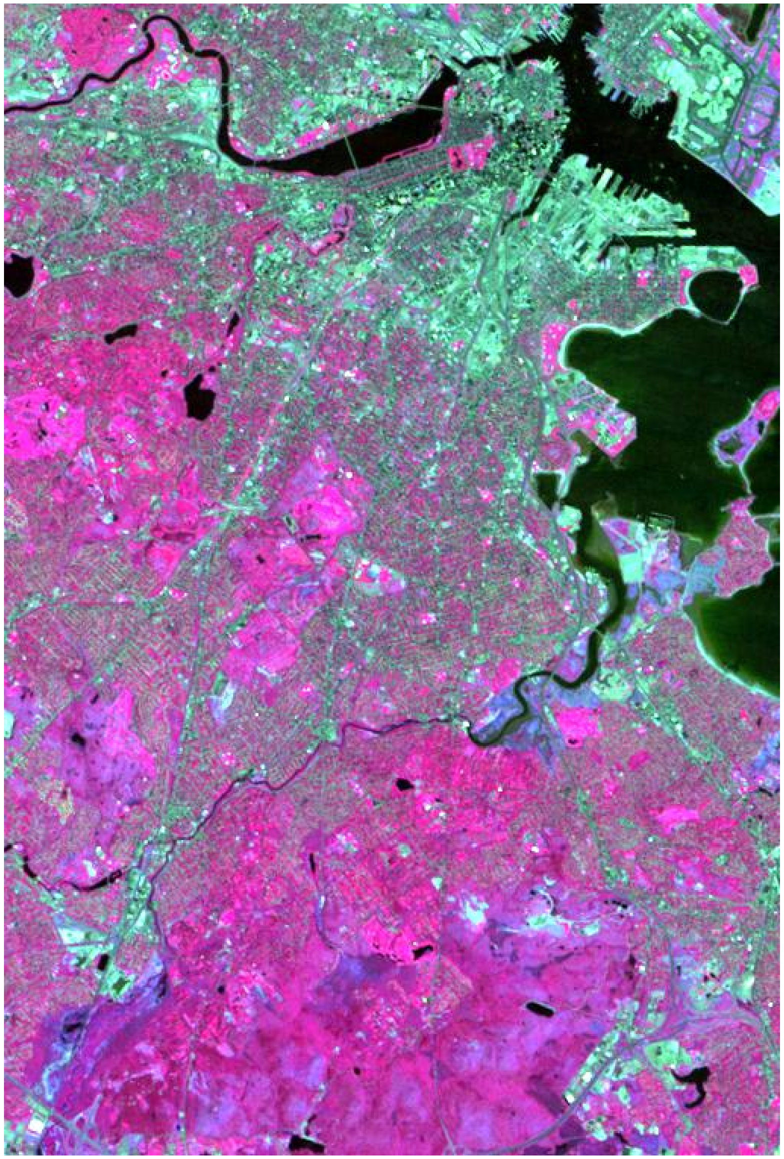
Landsat 432

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

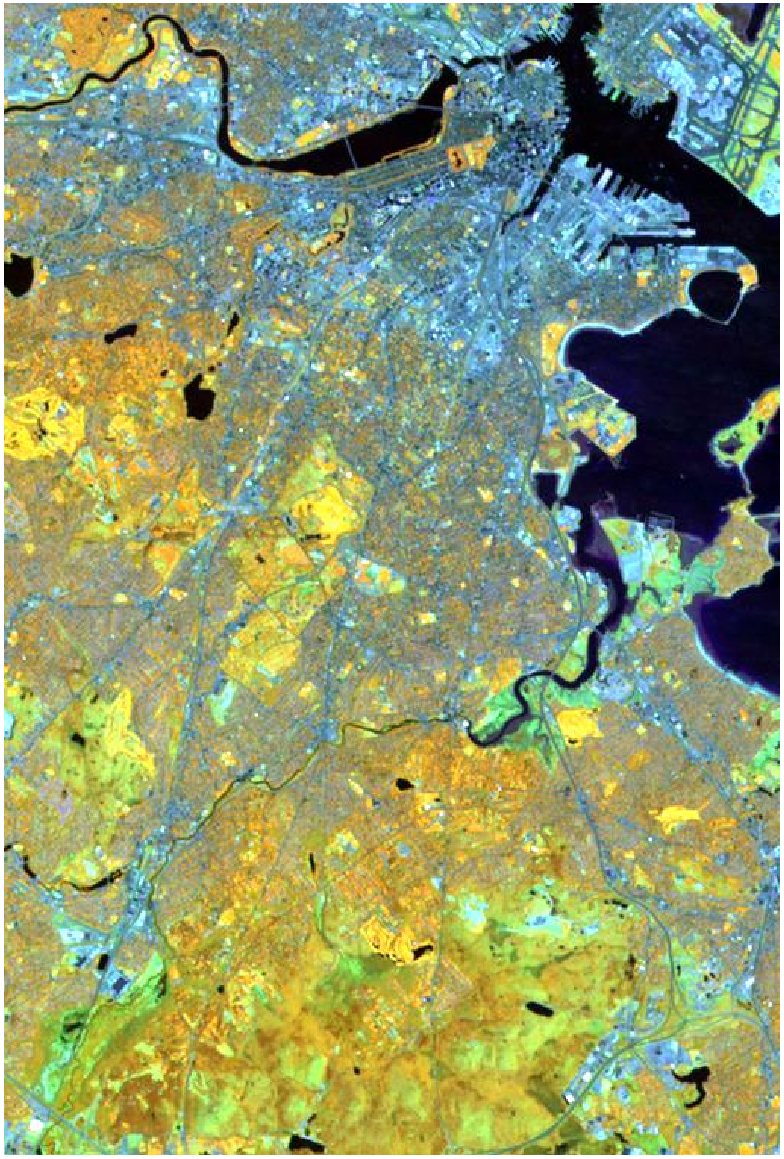
One reason for doing this is to help us visualize reflectance in the wavelengths we can’t see with our eyes!

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

2048 km swath

AVHRR, MODIS

- spatial resolution, 250m, 500m, 1000m
- spectral coverage, VIS, NIR, SWIR, MWIR, TIR
- calibrated @ ≤ 5% absolute

- global coverage, 2 days
- nadir only

Landsat

185 km

- spatial resolution, 15m, 30m
- spectral coverage, VIS, NIR, SWIR, TIR
- calibrated @ ≤ 10% absolute

- 16 day orbital repeat
- seasonal global coverage capability
- nadir only

IRS

146 km

- spatial resolution 36m, 72m
- spectral coverage, VIS, NIR
- relative calibration

- 22 day orbital repeat
- nadir only

SPOT

117 km via 2 @ 60 km

- spatial resolution 10m, 20m
- spectral coverage, VIS, NIR
- relative calibration

- 26 day orbital repeat
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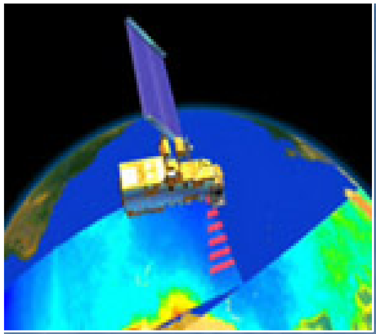
IKONOS

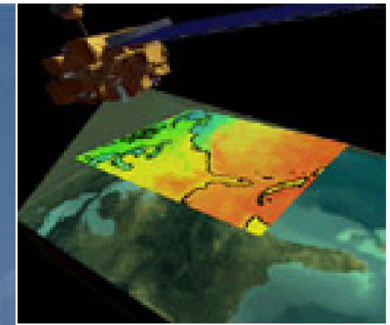
11 km

- spatial resolution 1m
- spectral coverage, panchromatic
- calibrated @ ≤ 10% absolute

- global coverage, years to ∞
- pointable, stereo capability



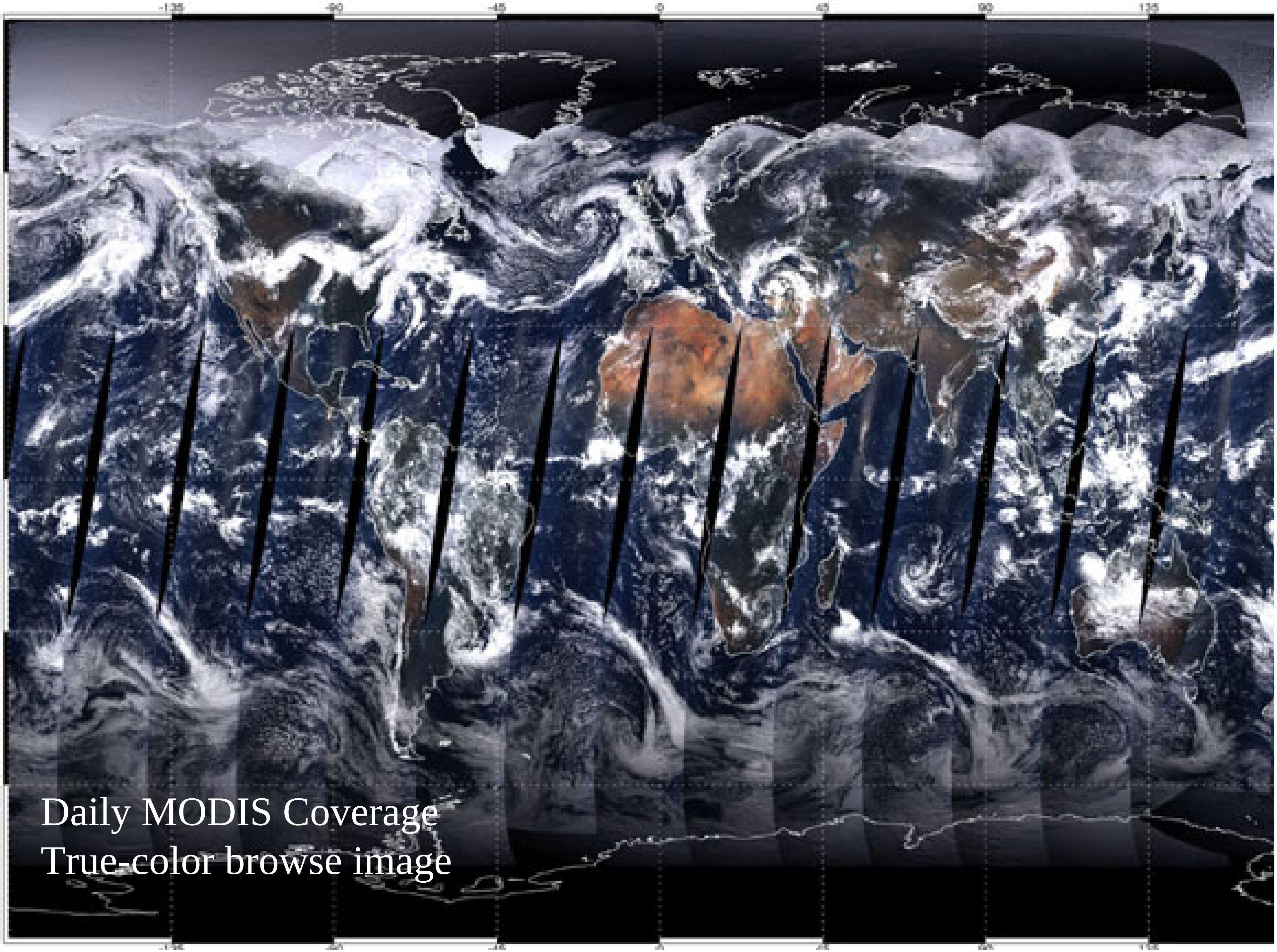
MODIS: System Characteristics



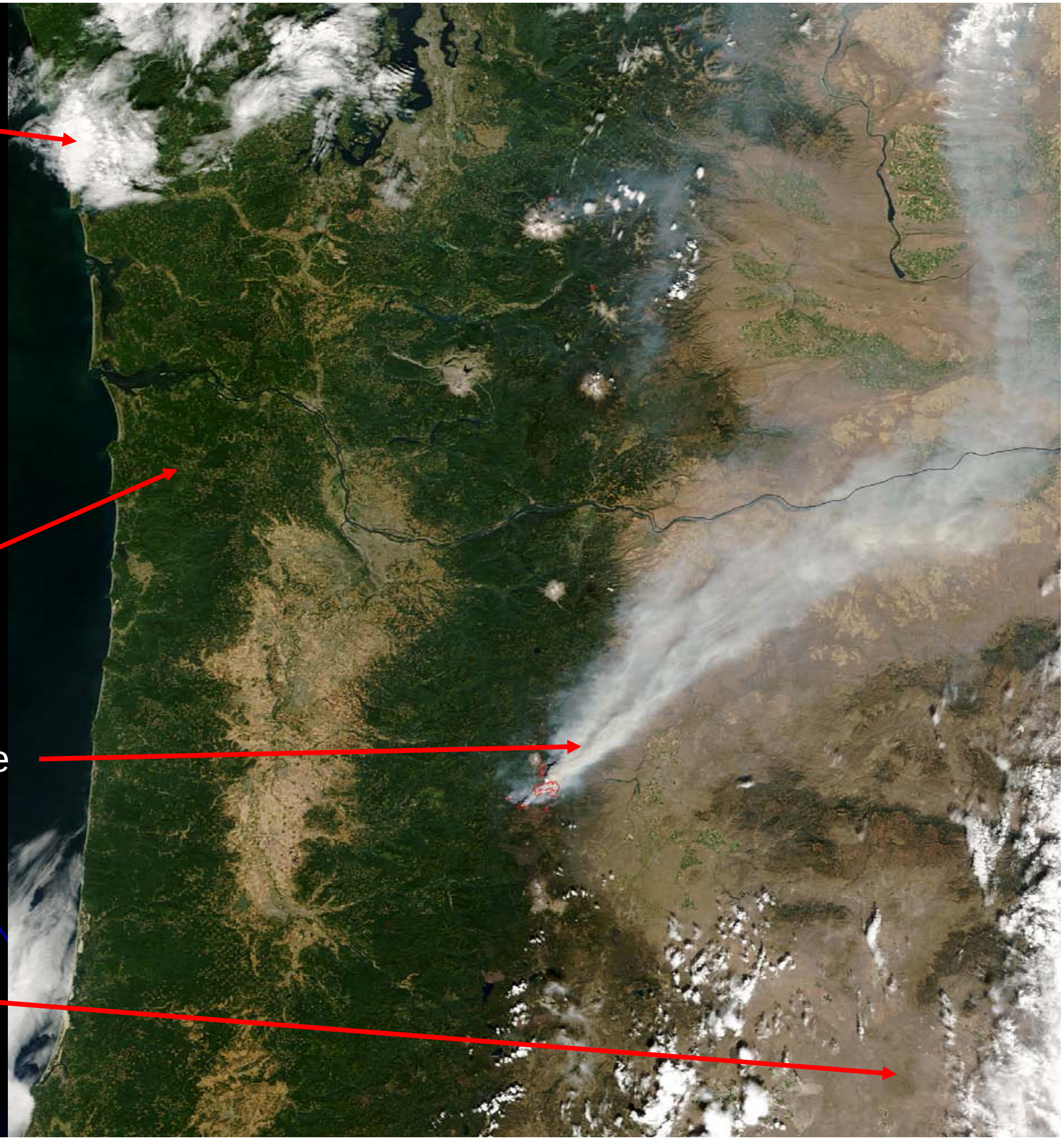
- MODIS Instrument Characteristics
  - 36 spectral bands, VNIR, SWIR, TIR (0.4–14 μm)
    - **Seven specifically designed for land observation**
  - Spatial resolutions at 250-, 500-, and 1000-m (nadir) depending on waveband
  - Repeat: 2-day global repeat, 1-day or less poleward of 30°
- Improvement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

MODIS Land Bands

Band number	Spatial resolution	Wavelength, nm	Waveband region
1	250 m	620-670	Red
2	250 m	841-876	Near-infrared
3	500 m	459-479	Blue
4	500 m	545-565	Green
5	500 m	1230-1250	Near-infrared
6	500 m	1628-1652	Shortwave infrared
7	500 m	2105-2135	Shortwave infrared


-135
-90
-45
0
45
90
135
Daily MODIS Coverage
True-color browse image

This MODIS image shows large parts of Oregon and Washington.



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?

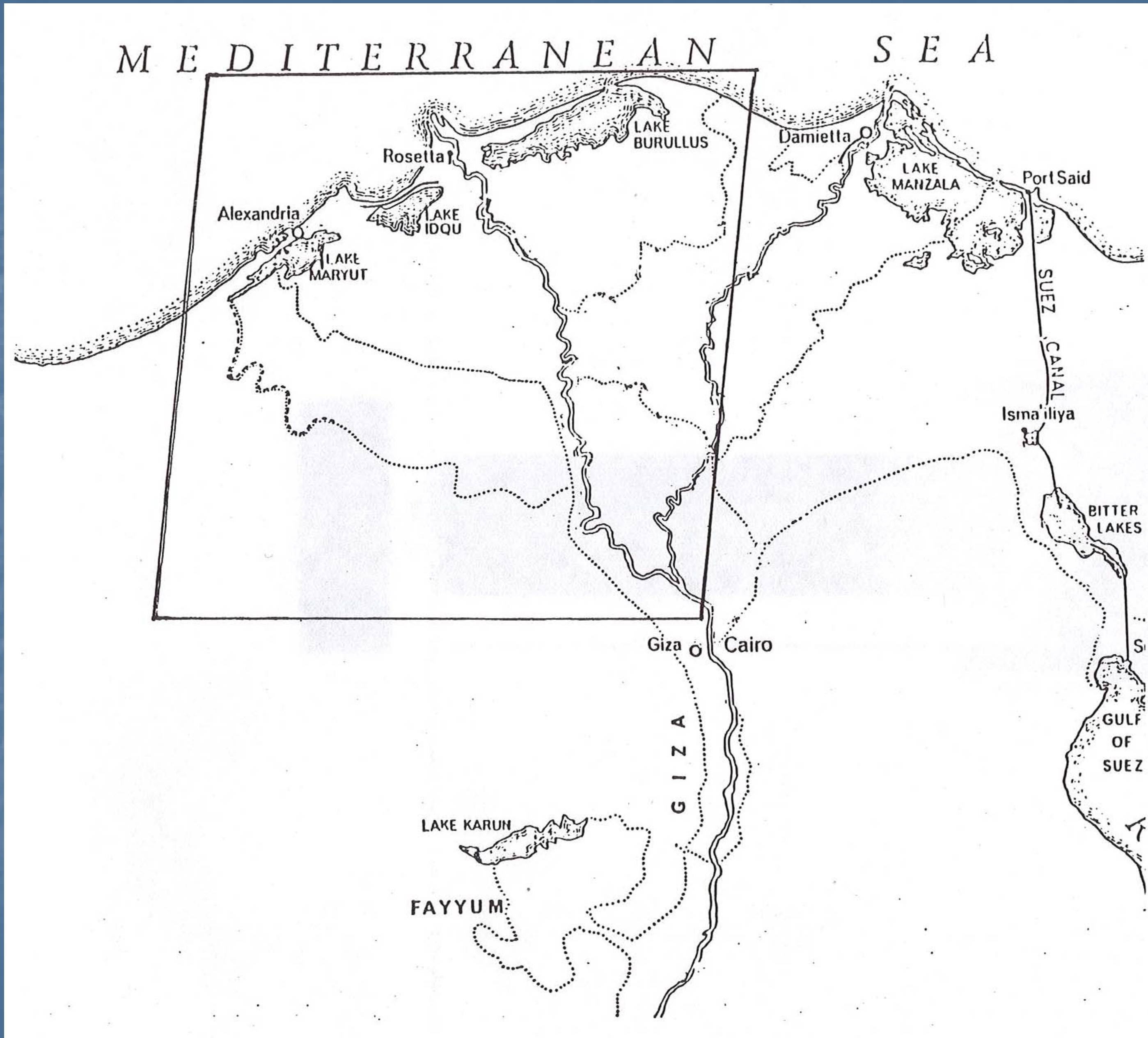
Outside the Nile Delta, the Western Desert is extremely arid and largely devoid of vegetation

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.

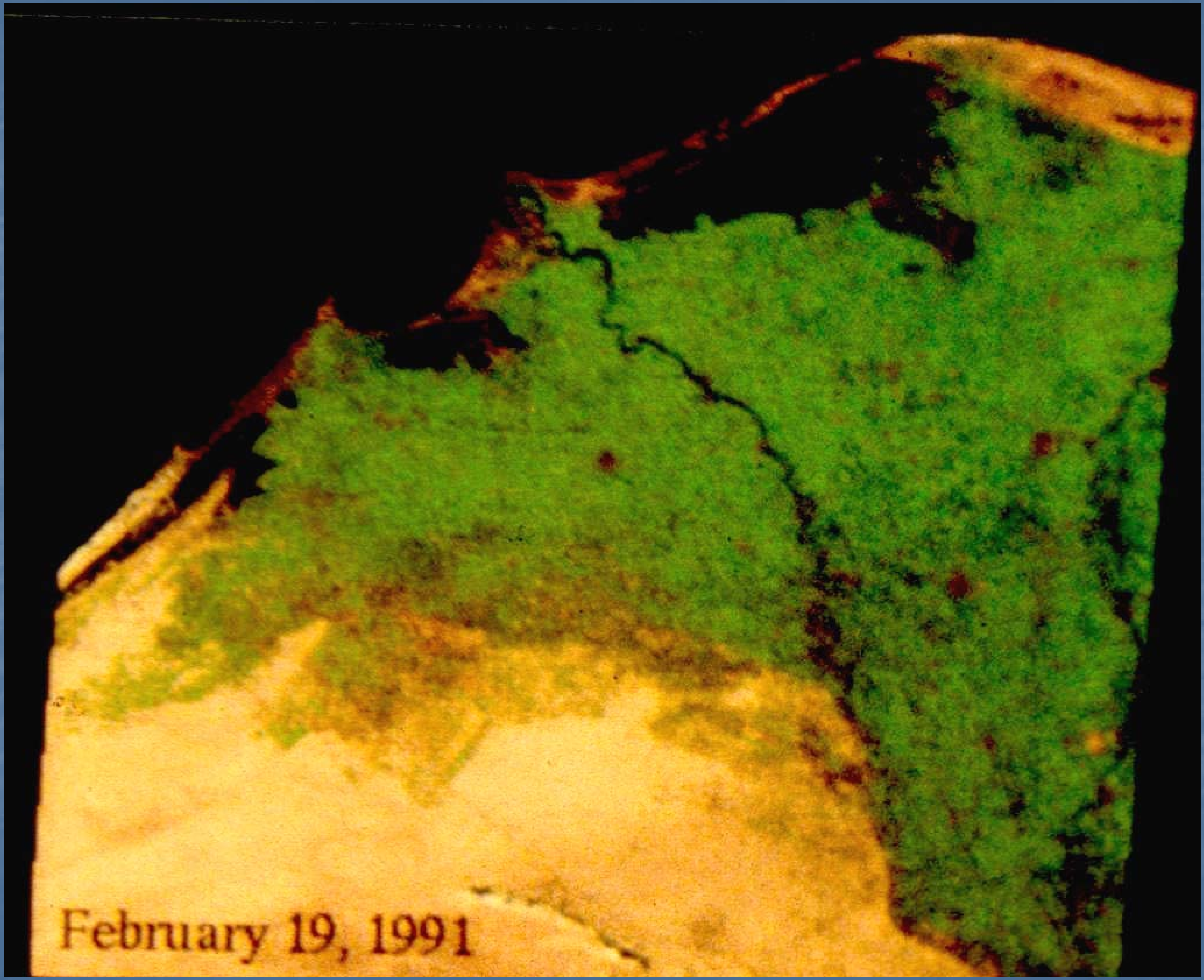
There are large extents in the Delta that have been abandon from agricultural production due to soil salinity problems

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



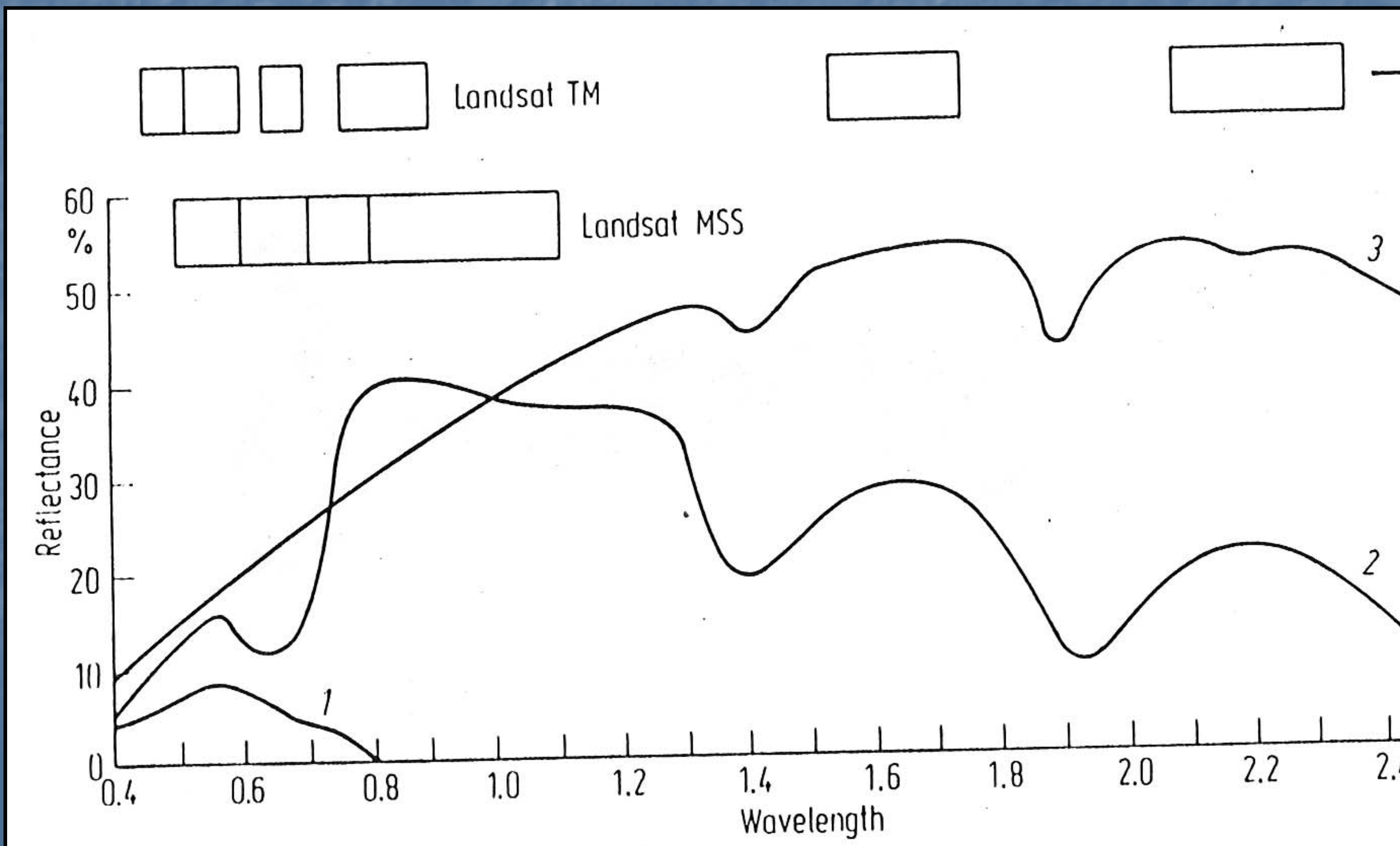
Landsat TM image of the study area



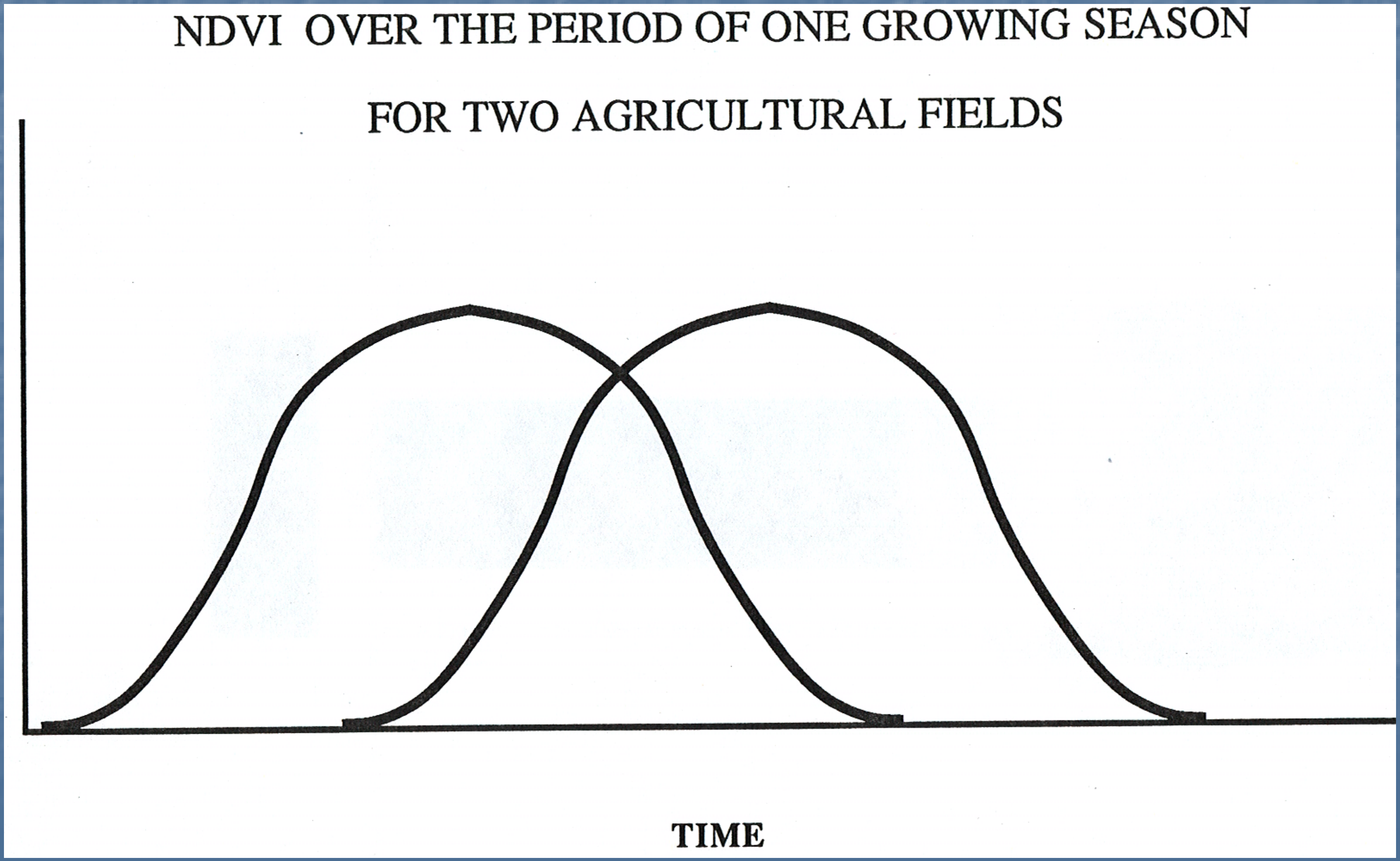
- **TRADITIONAL IMAGE ANALYSIS DOES NOT ACCOUNT FOR AGRARIAN PRACTICES COMMON IN THE REGION.**
  - CONSTANT AVAILABILITY OF IRRIGATION WATER AND MILD CLIMATE PERMIT FIELDS TO SUPPORT MULTIPLE CROPS IN ONE YEAR
  - FLEXIBILITY IN THE AGRICULTURAL GROWING CYCLES
  - SPECTRAL CONFUSION BETWEEN TEMPORARILY 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.

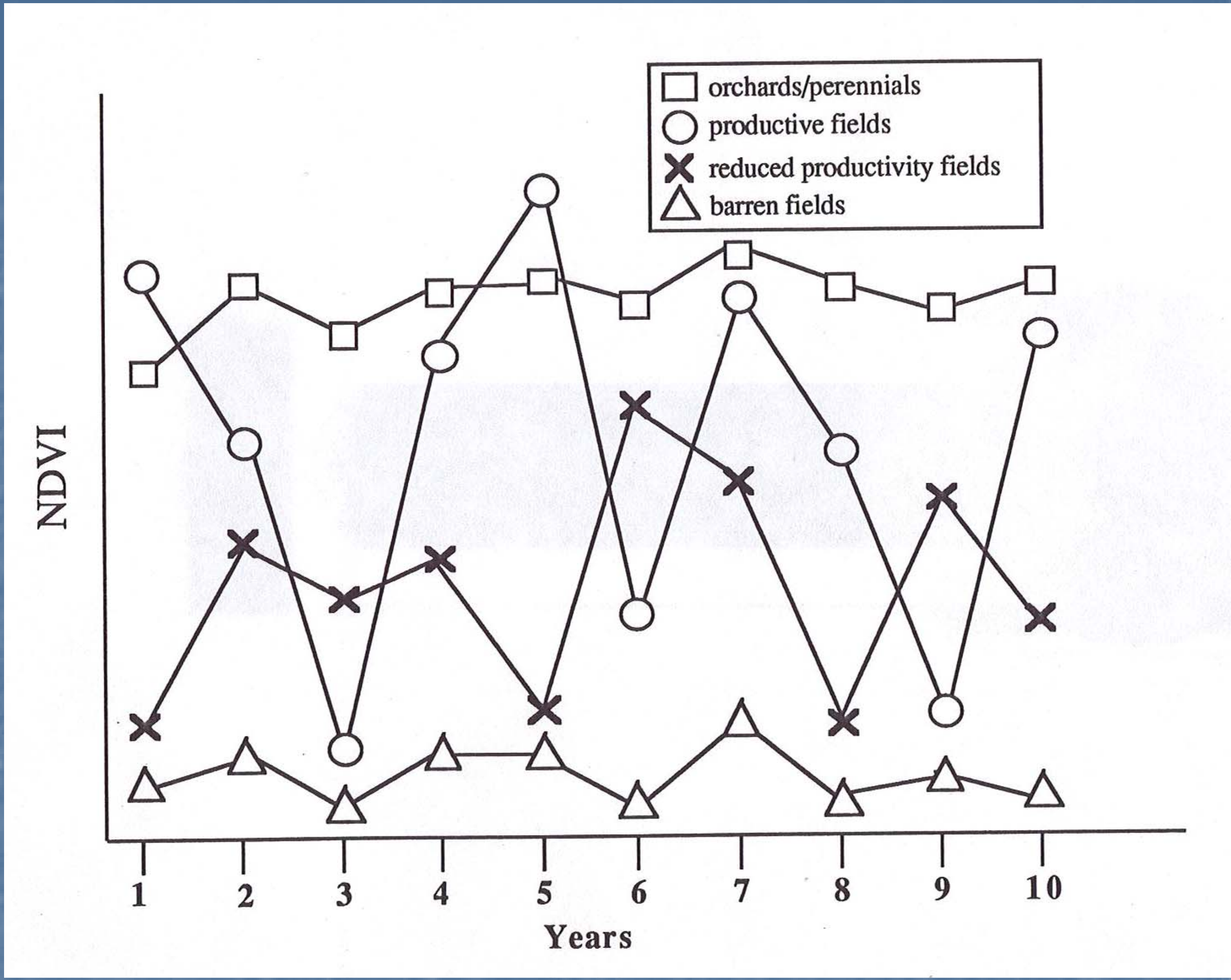
$$NDVI = \frac{IR - Red}{IR + Red} = \frac{TM4 - TM3}{TM4 + TM3}$$



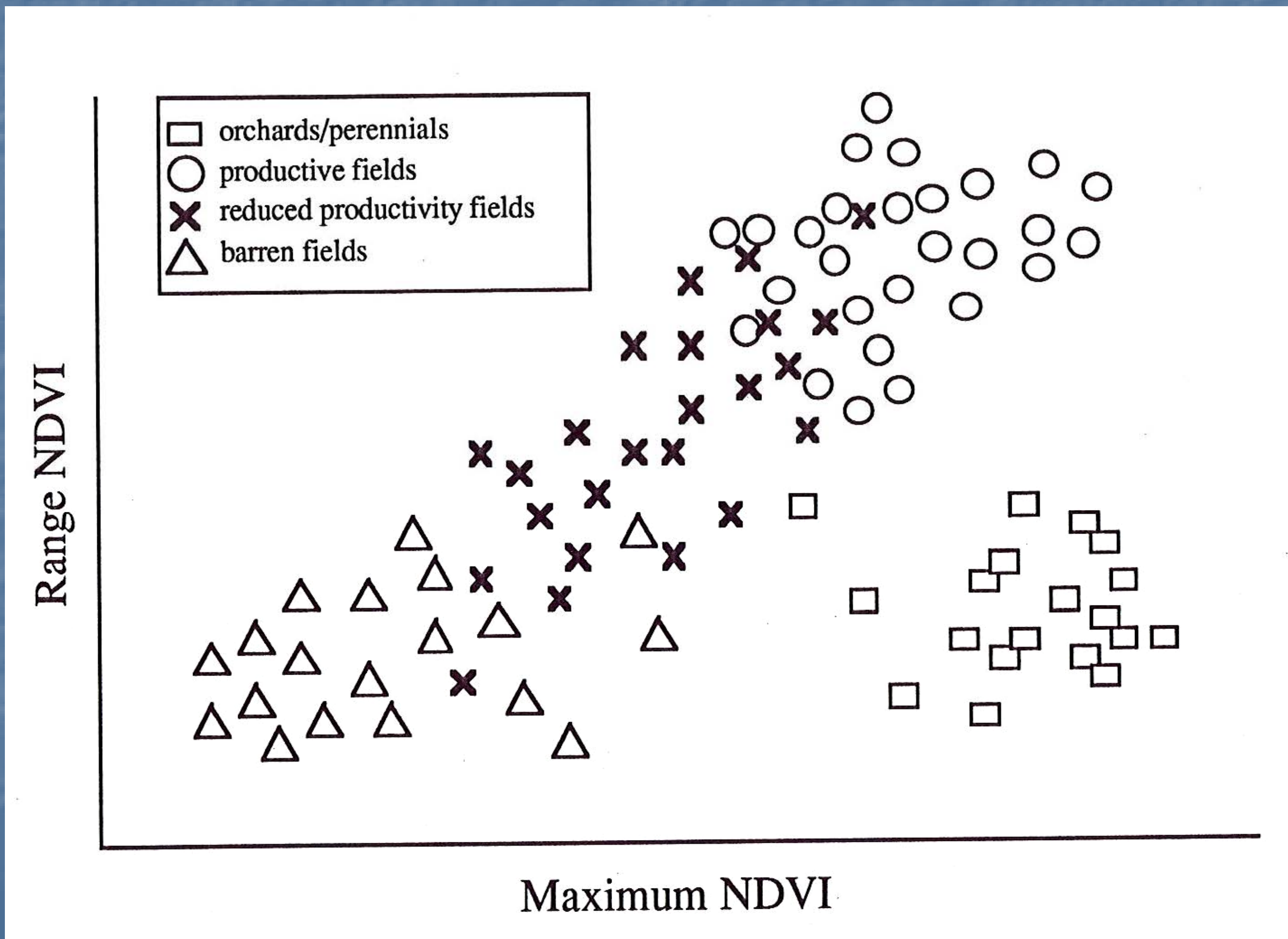
The variability in planting times for individual fields will result in some healthy, productive fields having low NDVI values in some images.



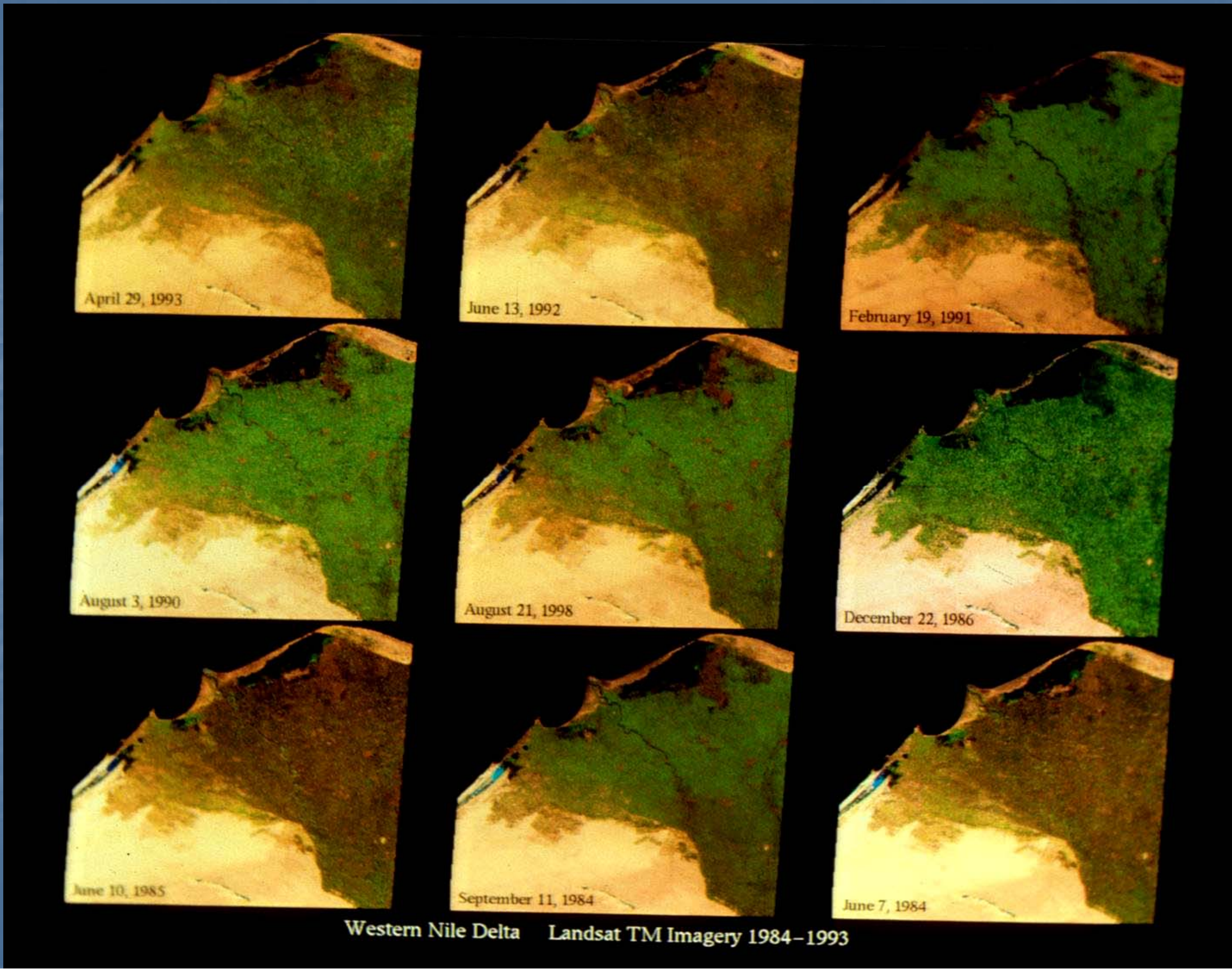
Conceptual model for the behavior of different land covers.



Strategy: Use the Max and Range of NDVI from many images to find areas chronically unproductive



9 Landsat TM images – Ranging over 9 years

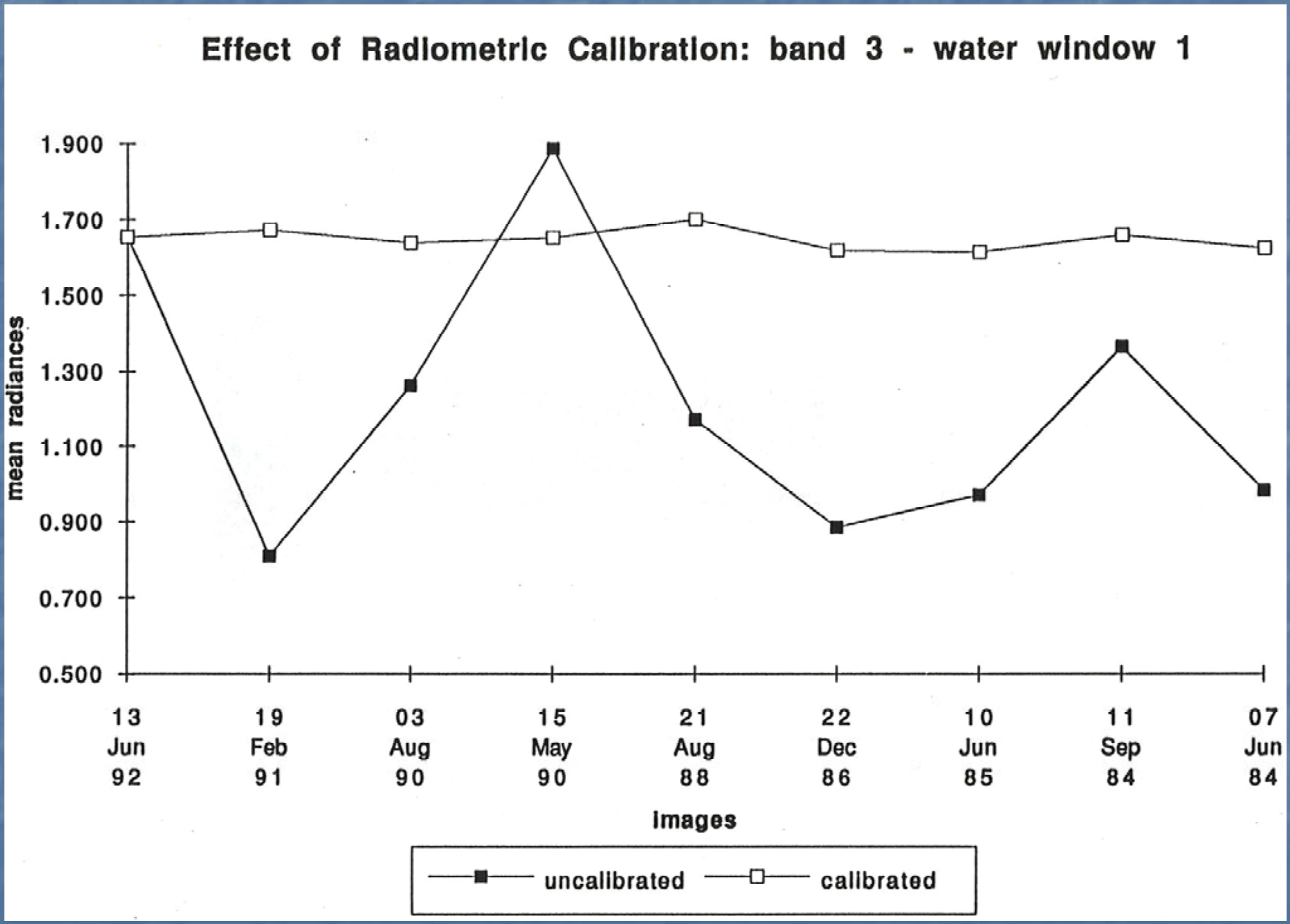


•Preprocessing:

Geometric Registration

Radiometric Matching

Calculation of NDVI

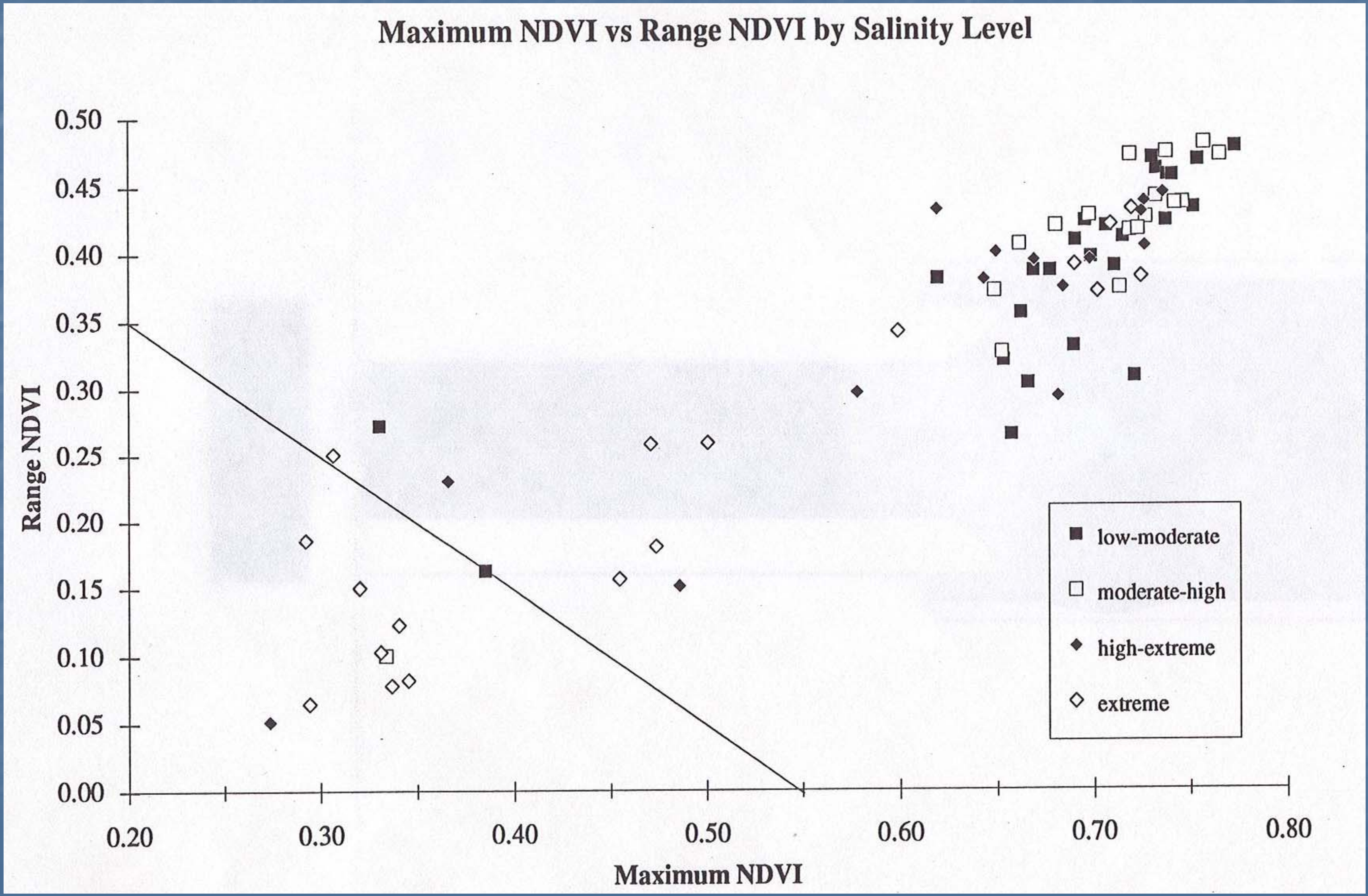


Notice the drop in variability for stable surface features following image "matching". Stable dark (ocean) and bright (desert) sites were used to correct each band to match the June 92 image.

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

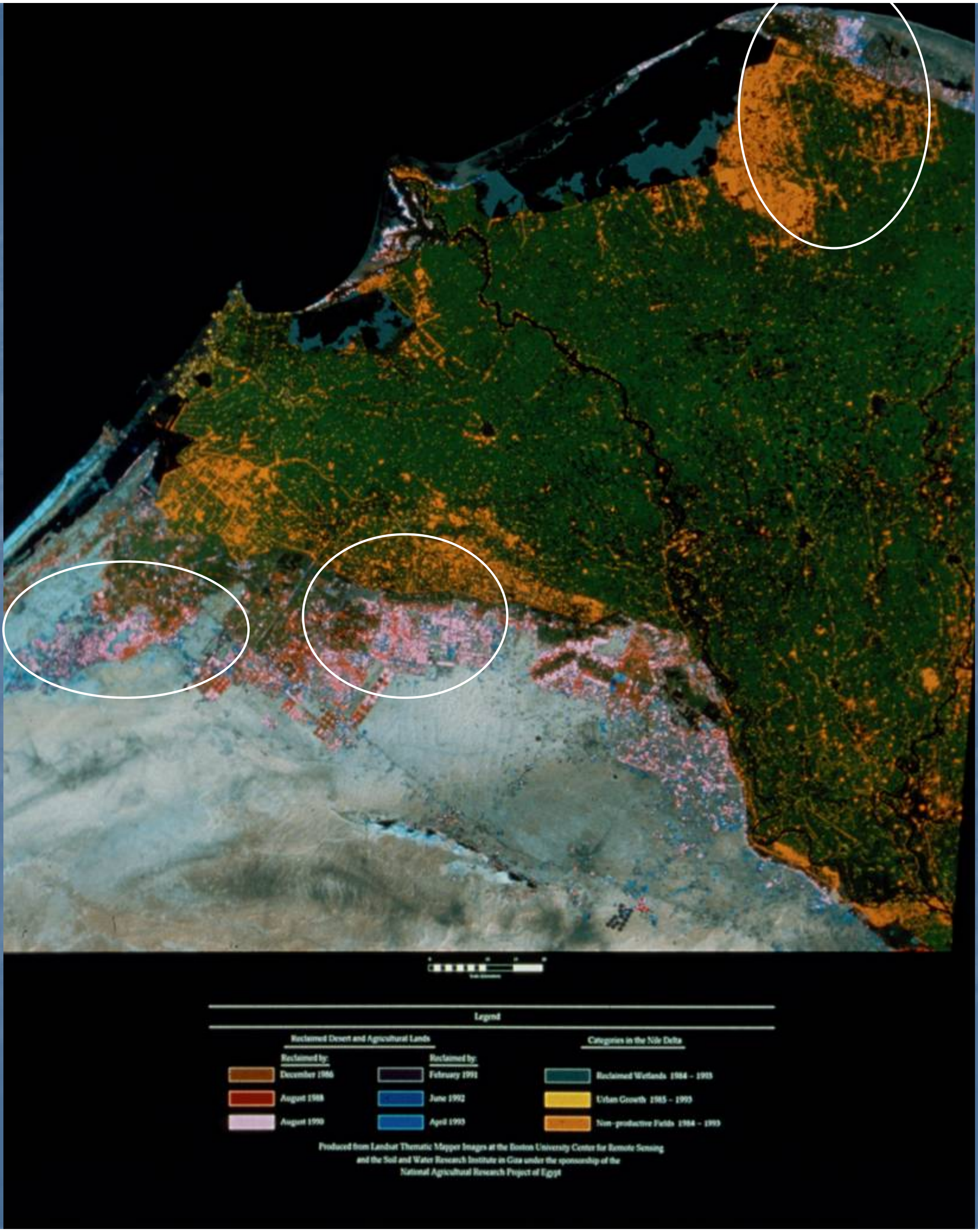


Monitoring Reclamation

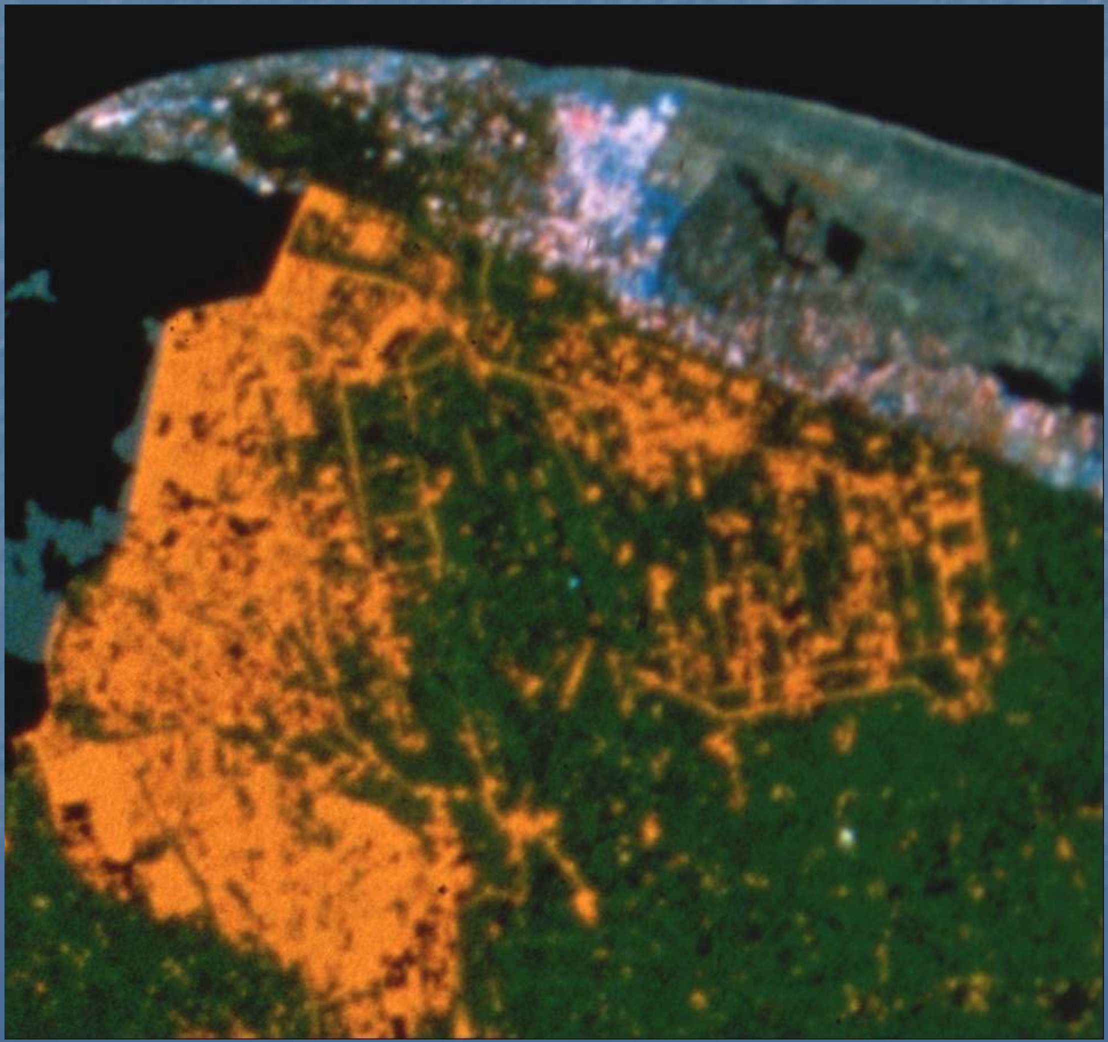
- Sites outside the Delta were identified as reclaimed any time NDVI surpassed a threshold
- Areas of urban growth (urbanization) was separated from the "reduced productivity" class by use of the spatial proximity to existing urban areas. (it was interesting to find that spectrally, urban areas in the 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)



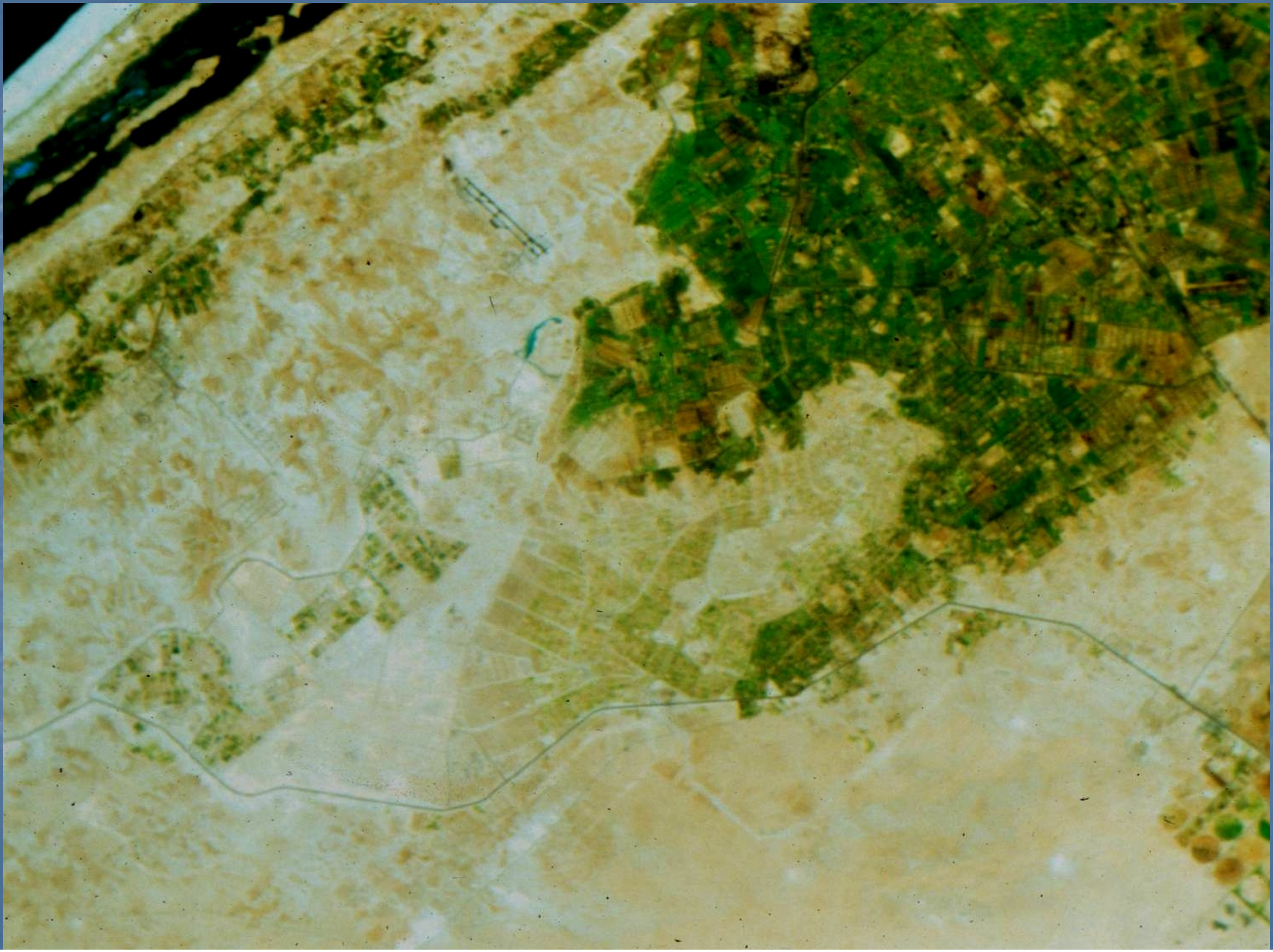
There are extensive salinity problems near Lake Burullus. Note the expansion of agriculture onto the beach areas along the Mediterranean.



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

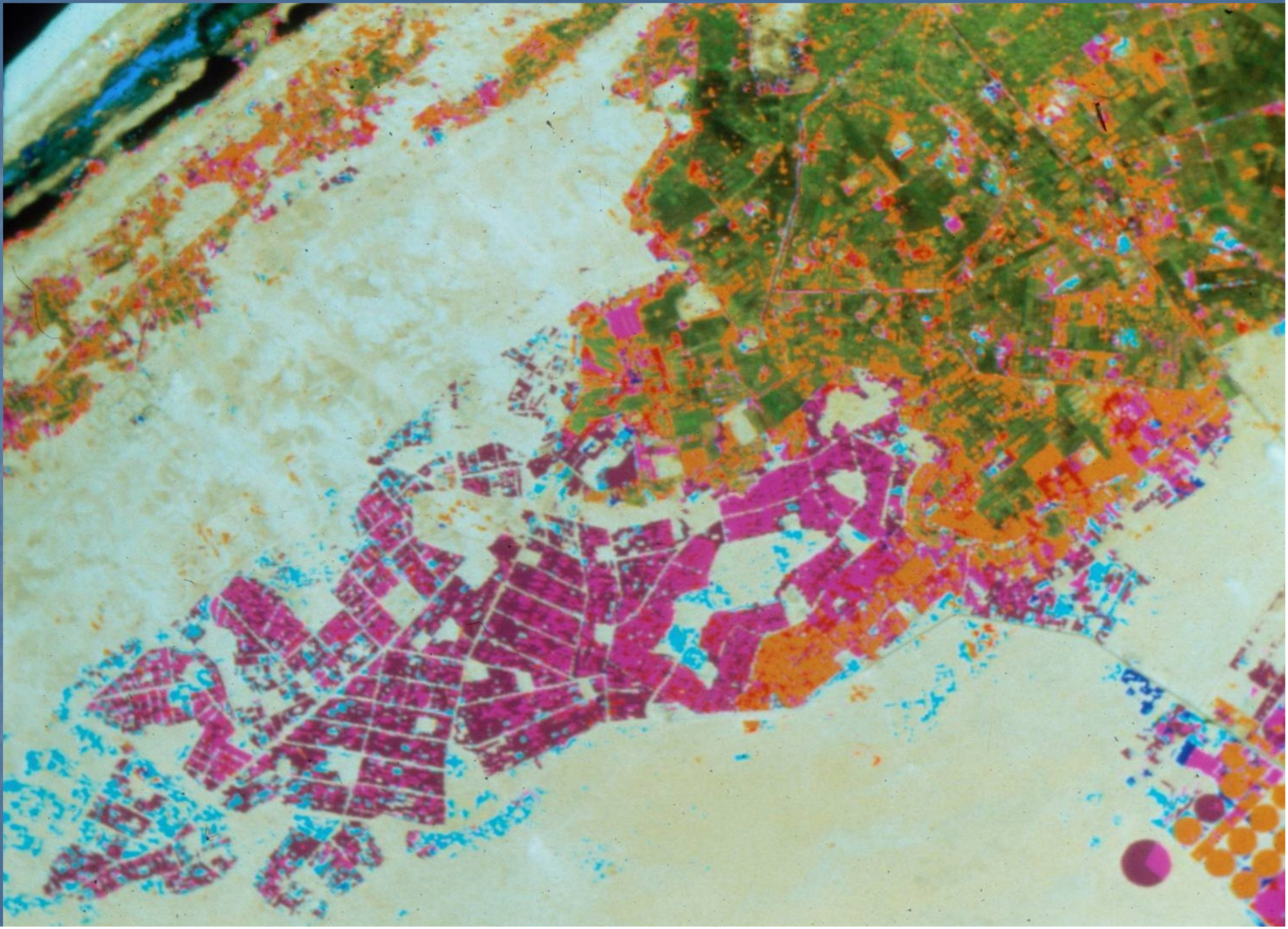
1986



1991

1992

Final Map: colors are the different years of reclamation



Maps are untested hypotheses without accuracy assessment!

ACCURACY ASSESSMENT

	FIELD ASSESSMENTS									
Map Label	Sites	urban	urbaniz	red. prod.	agric. delta	agric. desert	reclaim	wet. reclaim	other	**user's accuracy**
urban	28	**28**								100.00%
urbanization	17	4	**8**	1	4					47.06%
reduced productivity	31	5.5*	2.5*	**19**	3				1	61.29%
agriculture in delta	75				**75**					100.00%
agriculture in desert	13					**11**	1		1	84.62%
reclamation	27					6	**18**		3	66.67%
wetlands reclaimed	4							**3**	1	75.00%
other	70								**70**	100.00%
totals	265									87.55%

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)

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

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

THE GROWTH OF URBAN CENTERS ONTO PRODUCTIVE LANDS WAS SLOWER THAN EXPECTED. LESS THAN 1% OF HEATHY AGRICULTURAL LANDS WERE CONVERTED TO URBAN LAND USE BETWEEN 1984 AND 1990.

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 Jinfa, Institute of Geography CAS

Li Xiaowen, IRSA

Wang Tongsan, Economic Forecasting Center

Huang Xiuhua, IRSA

Liang Youcai, State Information Center

Seto, K.C., Woodcock, C.E., Song, C., Huang, X., Lu, J., and R.K. Kaufmann, 2002. Monitoring land-use change in the Pearl River Delta using Landsat TM, *International Journal of Remote Sensing*, 23(10):1985-2004.

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)

Crisis or Opportunity?

Cities as problems	Cities as solutions
• Unemployment • Environmental degradation • Loss of agricultural land • Pressure on natural resources (energy, water, land) • Deficiencies in urban services • Deterioration of infrastructure • Inadequate housing • Consumption patterns	• Driving forces in economic growth • Efficient use of infrastructure • Delivery of health services • Sanitation • Education • "Saving land for nature" • Efficient natural resource use

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%)

Source: C. Fan, 2004.

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

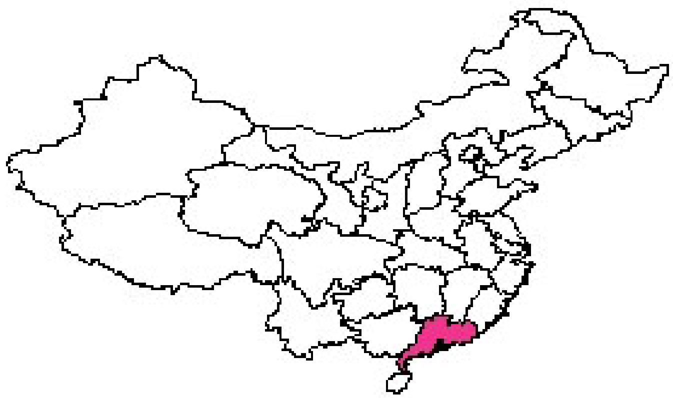
→

Implications for land use

- Massive migrations
- Rapid urbanization
- Grain-based to meat-based diets

Why Pearl River Delta, Guangdong Province?

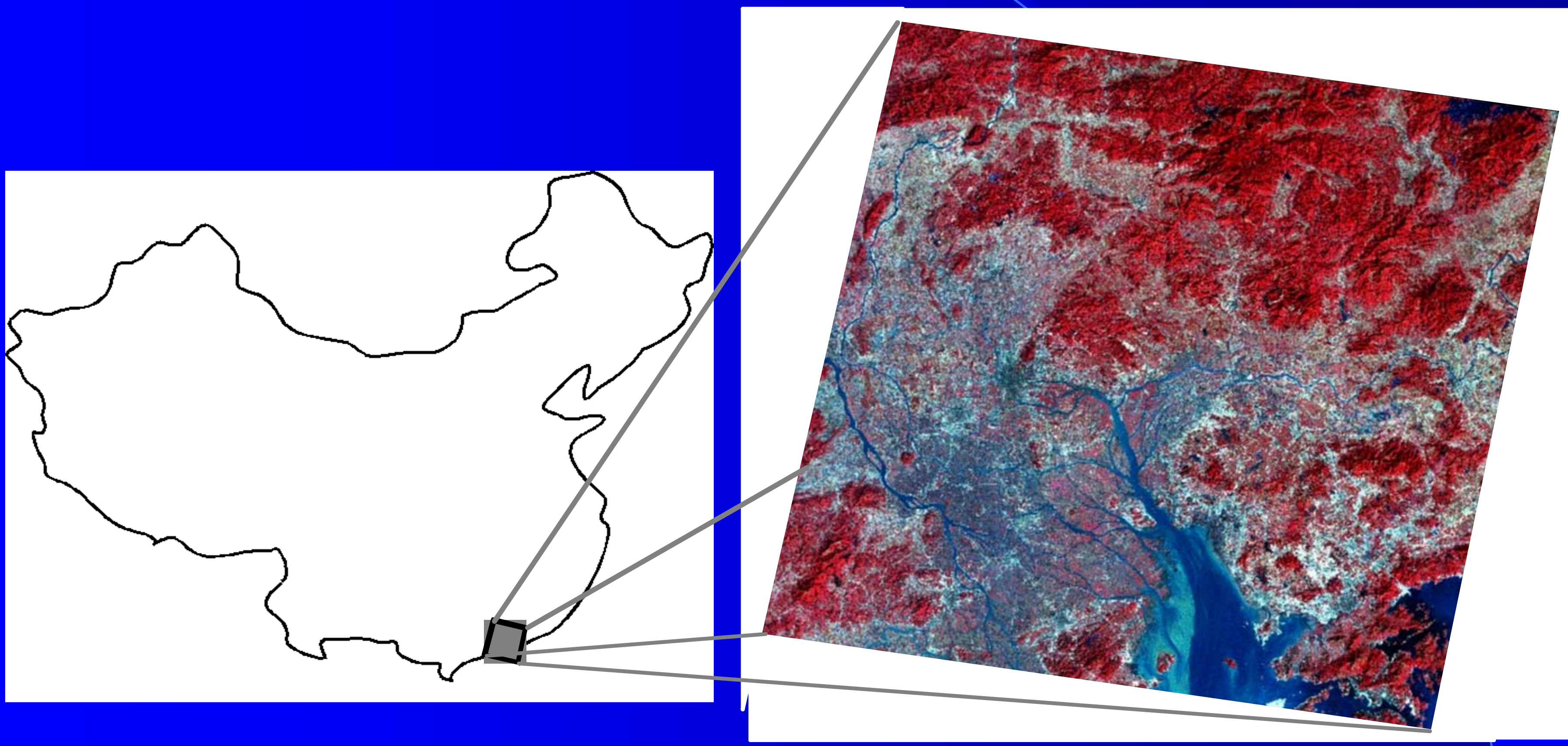
- 1988 - 1996 real GDP growth: 350-550%
- Major agricultural region and national leader in production of:
  - lychees, bananas, pond fish, sugar cane
- Special Economic Zones
- Geographic proximity to Hong Kong
- Cultural ties to overseas Chinese investors



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



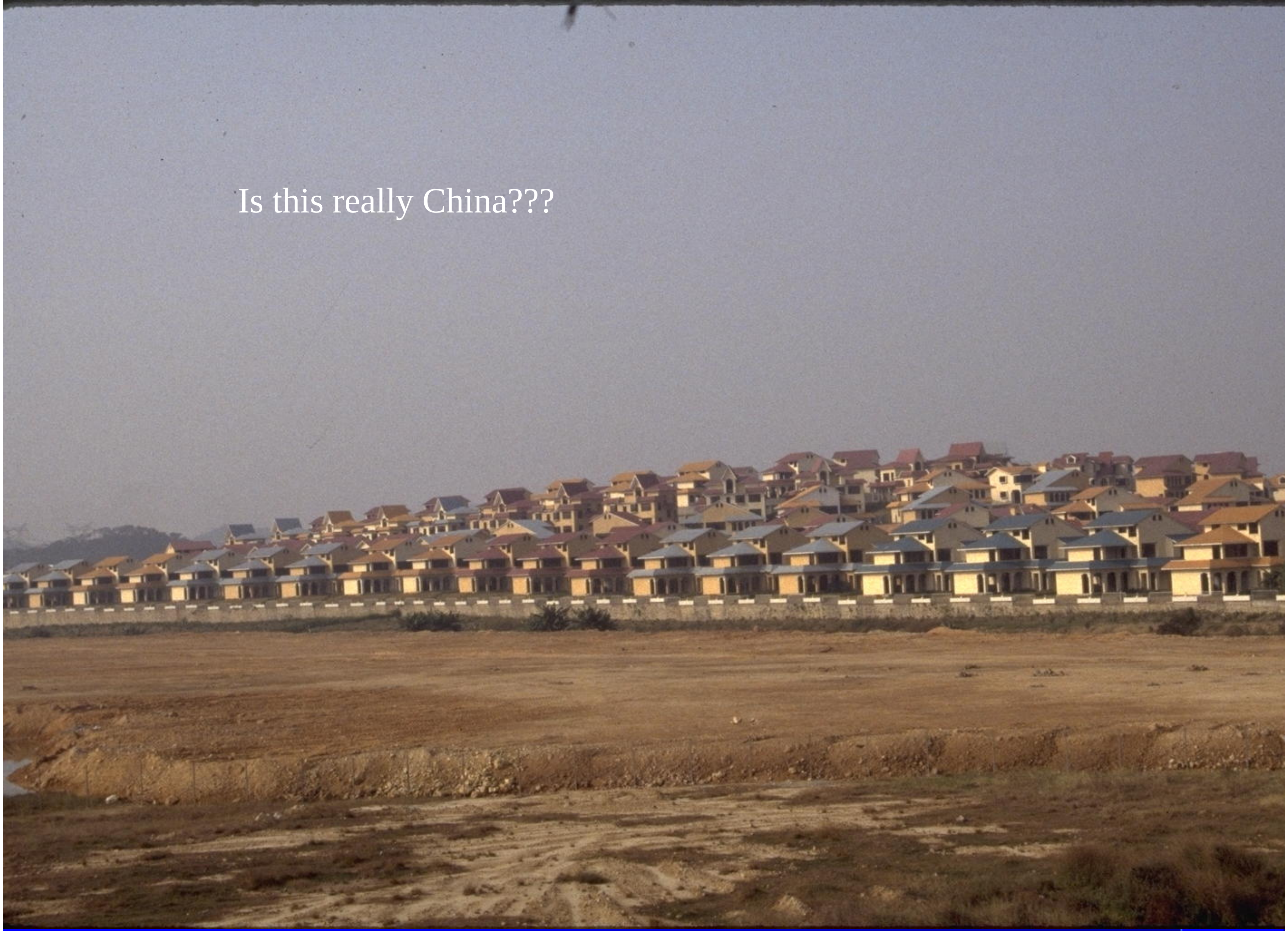
Landsat TM 432 (RGB) 12.30.95

东部集团
华安保险


3/4/2002

深圳发展銀行
深圳市古玩城
收藏家的乐园
深圳市古玩城
3/4/2002 0

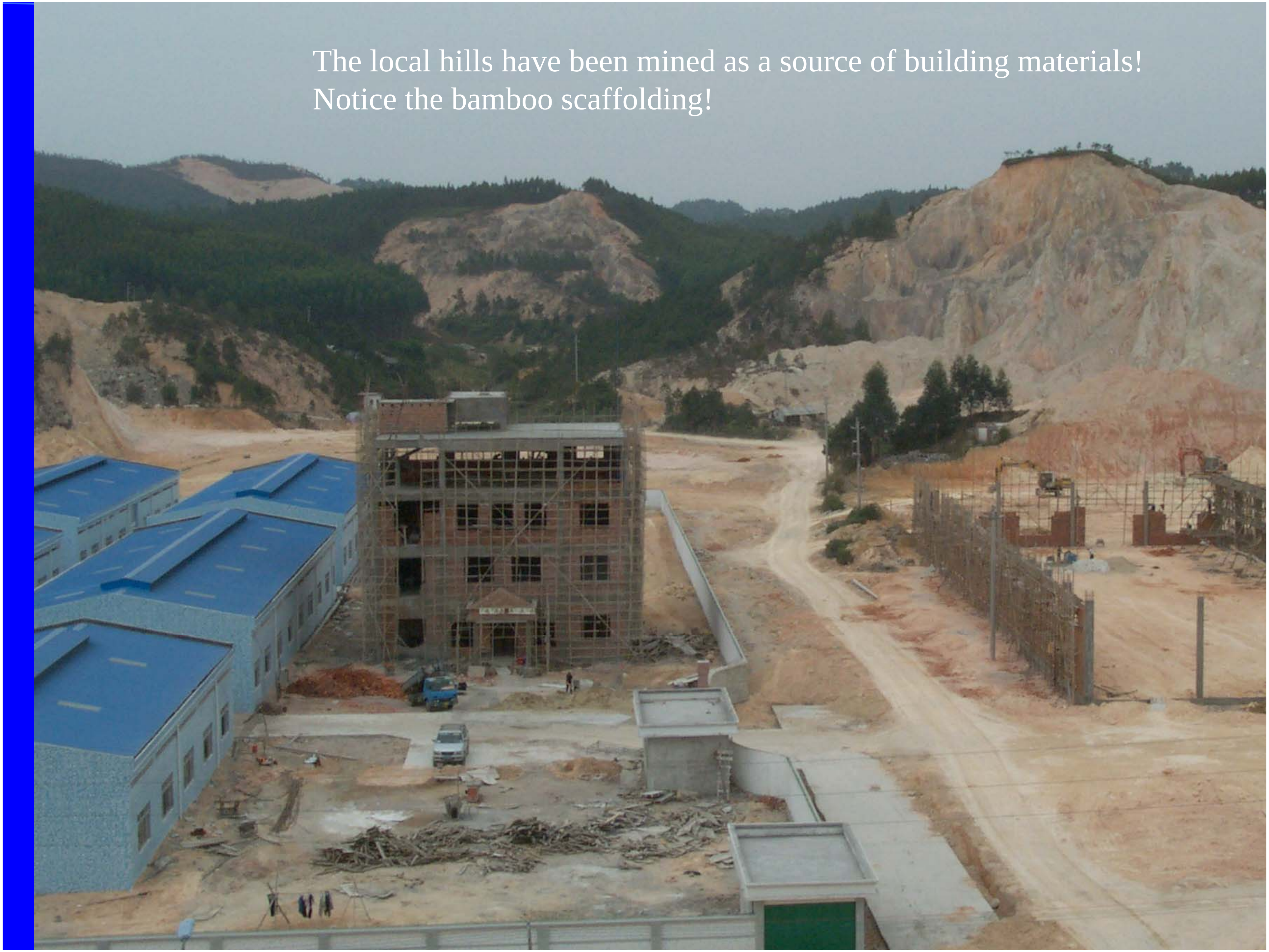

3/10/2002 04:00


Is this really China???

Typical urban dwellings
(Guong Zhou)

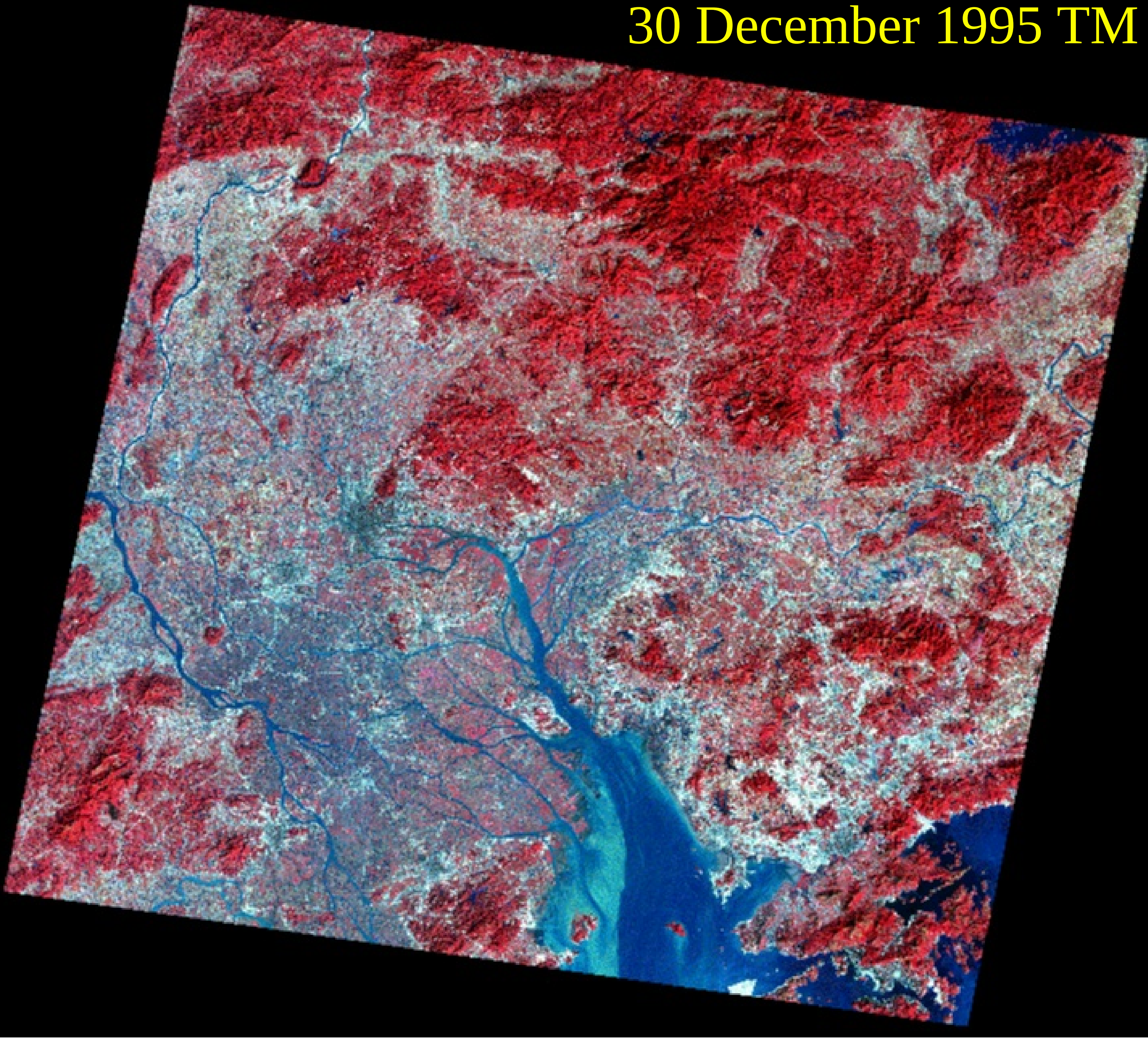

3/5/2002 08:58

Buildings of several stories are being built with bamboo scaffolding and without the use of cranes! Huge amounts of manual labor!



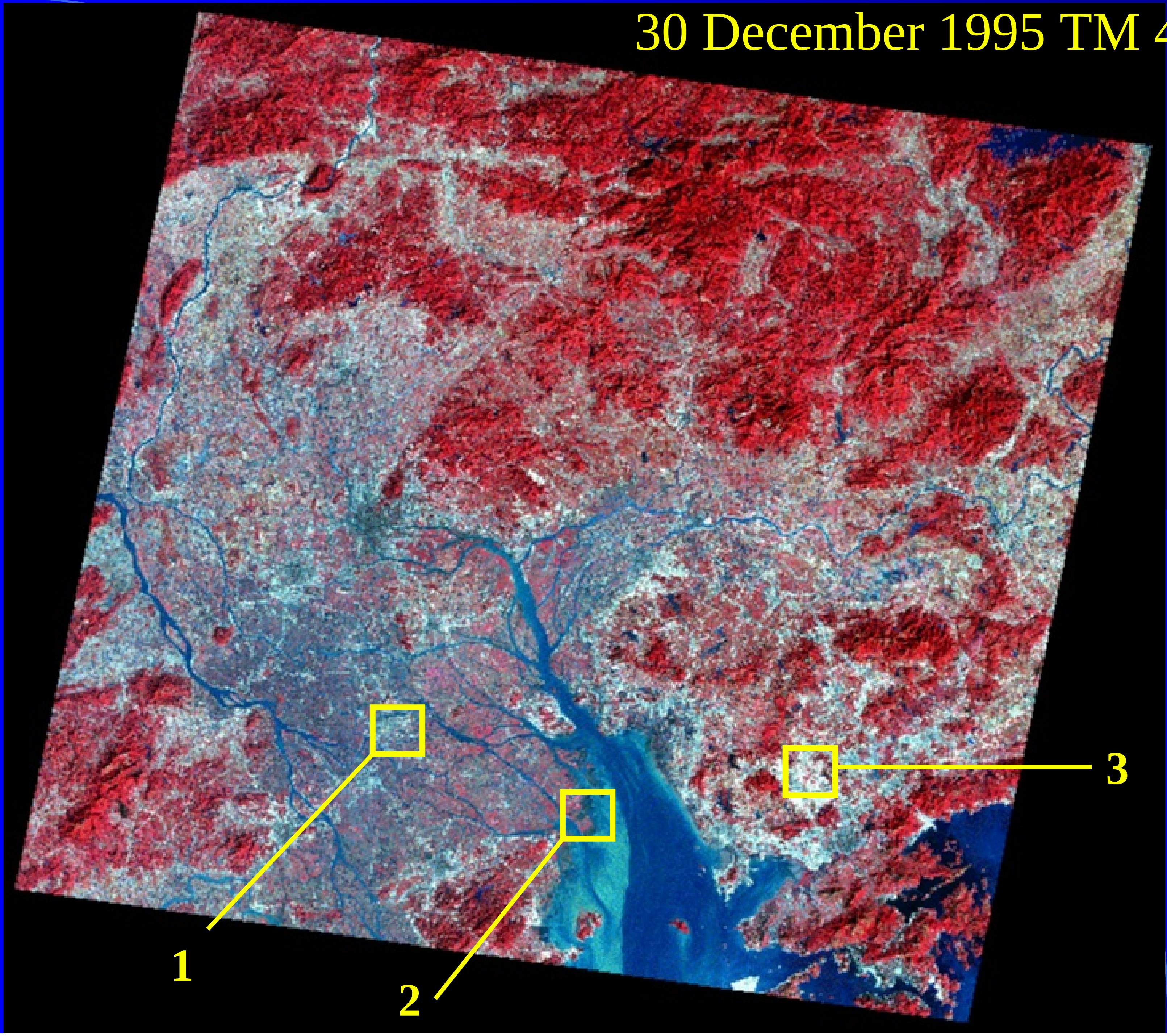
The local hills have been mined as a source of building materials!
Notice the bamboo scaffolding!

30 December 1995 TM 432



Stable and Change Land-Use/Cover Classes

Stable	Change
Water	Water → Fish pond Water → Agriculture Water → Transition Water → Urban
Forest	Forest → Water Forest → Transition Forest → Urban
Shrub	Shrub → Water Shrub → Transition Shrub → Urban
Fish Pond	Fish pond → Transition
Agriculture	Agriculture → Water Agriculture → Fish pond Agriculture → Transition Agriculture → Urban
Transition	Transition → Urban
Urban	

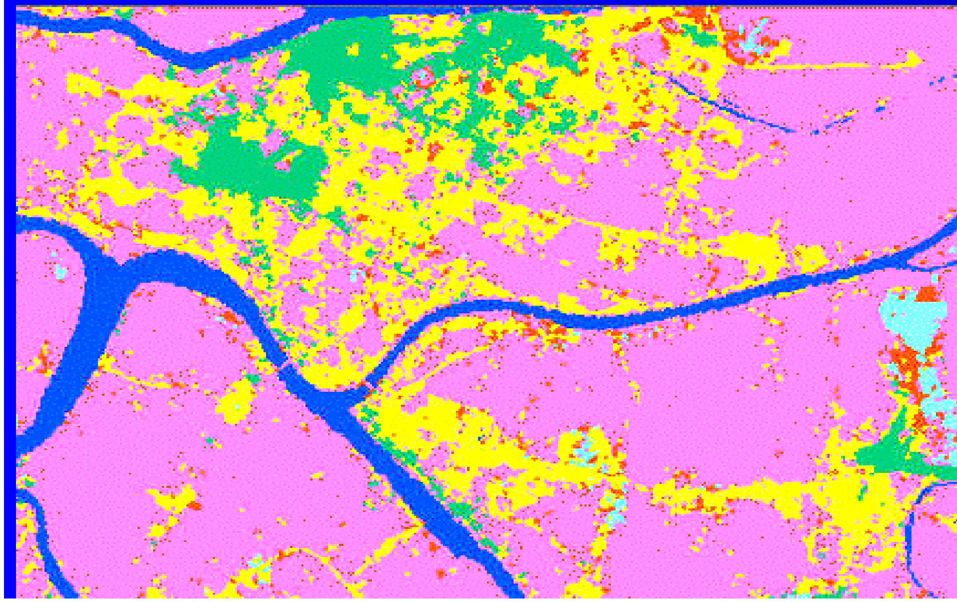


30 December 1995 TM 432
1
2
3

10 December 1988 TM 432

3 March 1996 TM 432

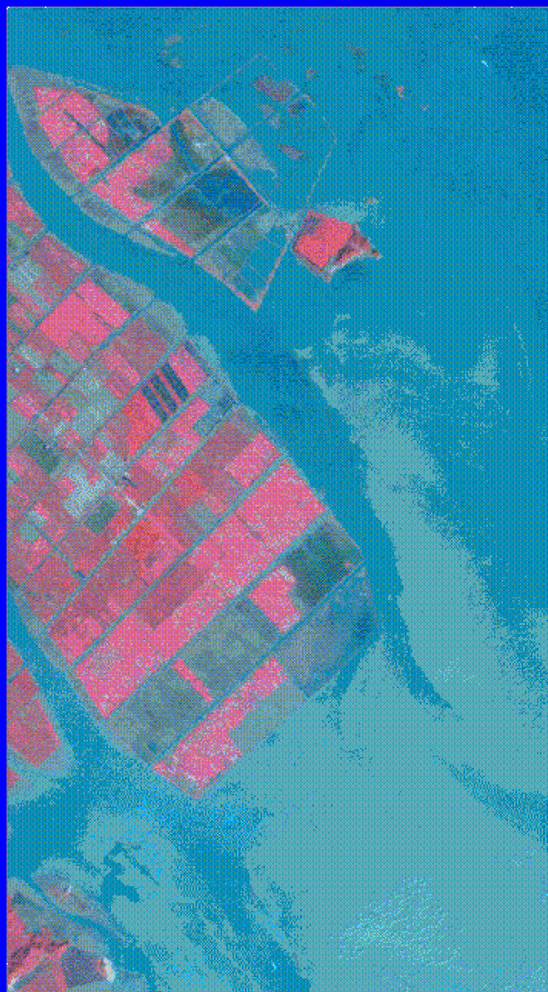
Land-Use Change Map



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

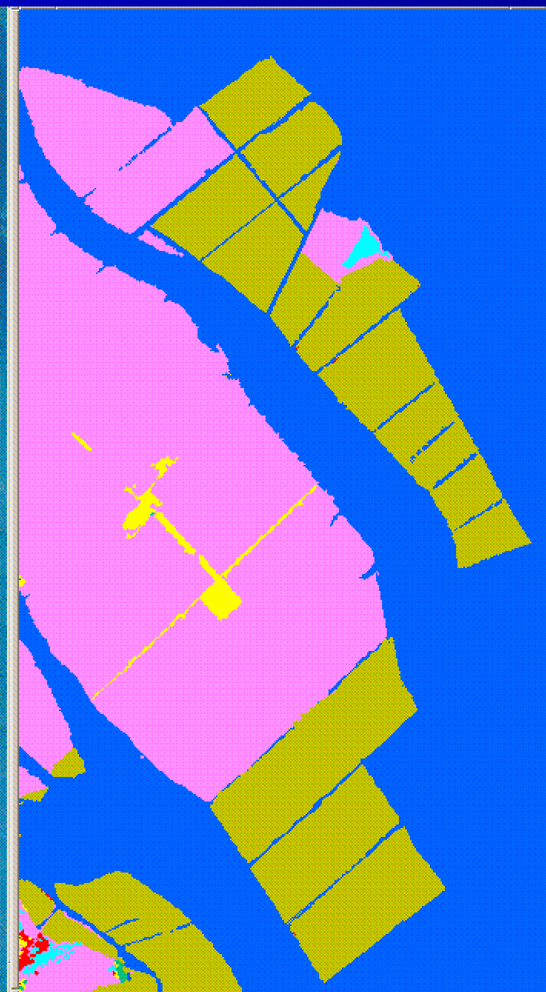
5 km

10 December 1988 TM 432



3 March 1996 TM 432

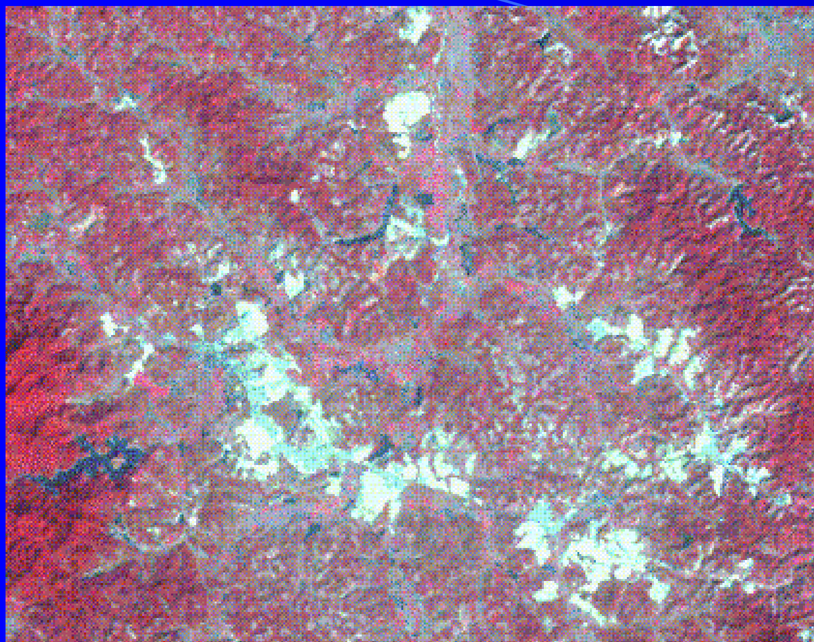
Land-Use Change Map



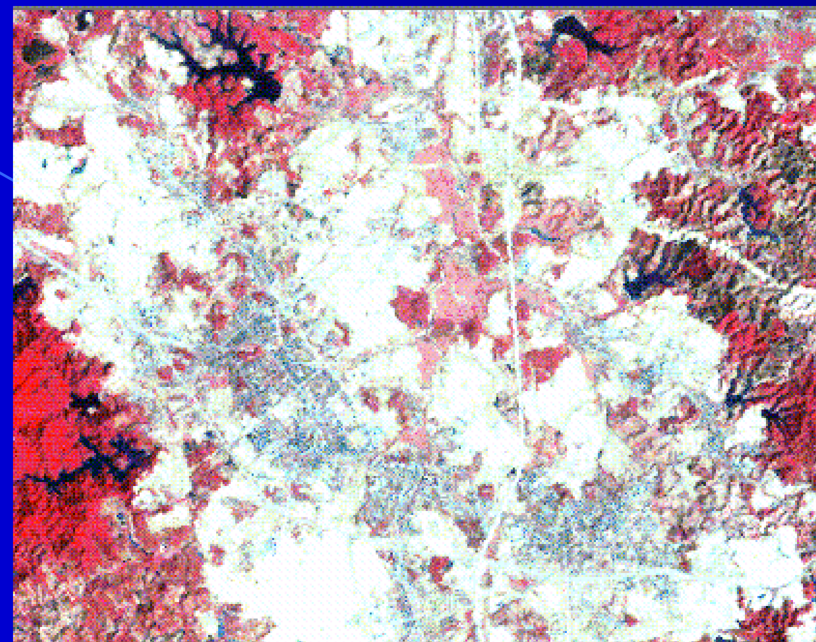
5 km

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

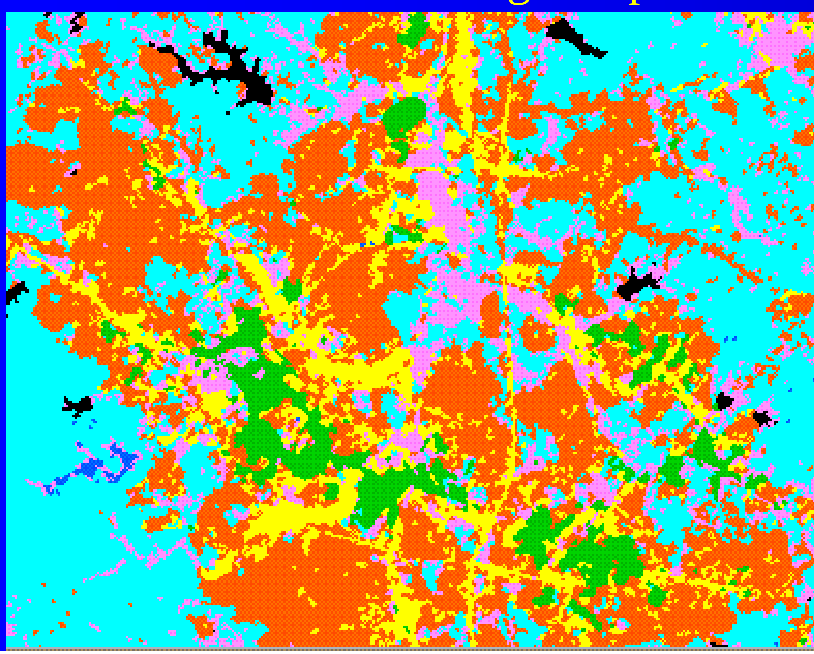
10 December 1988 TM 432



3 March 1996 TM 432



Land-Use Change Map



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

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

Department of Geography

Boston University

Boston, MA

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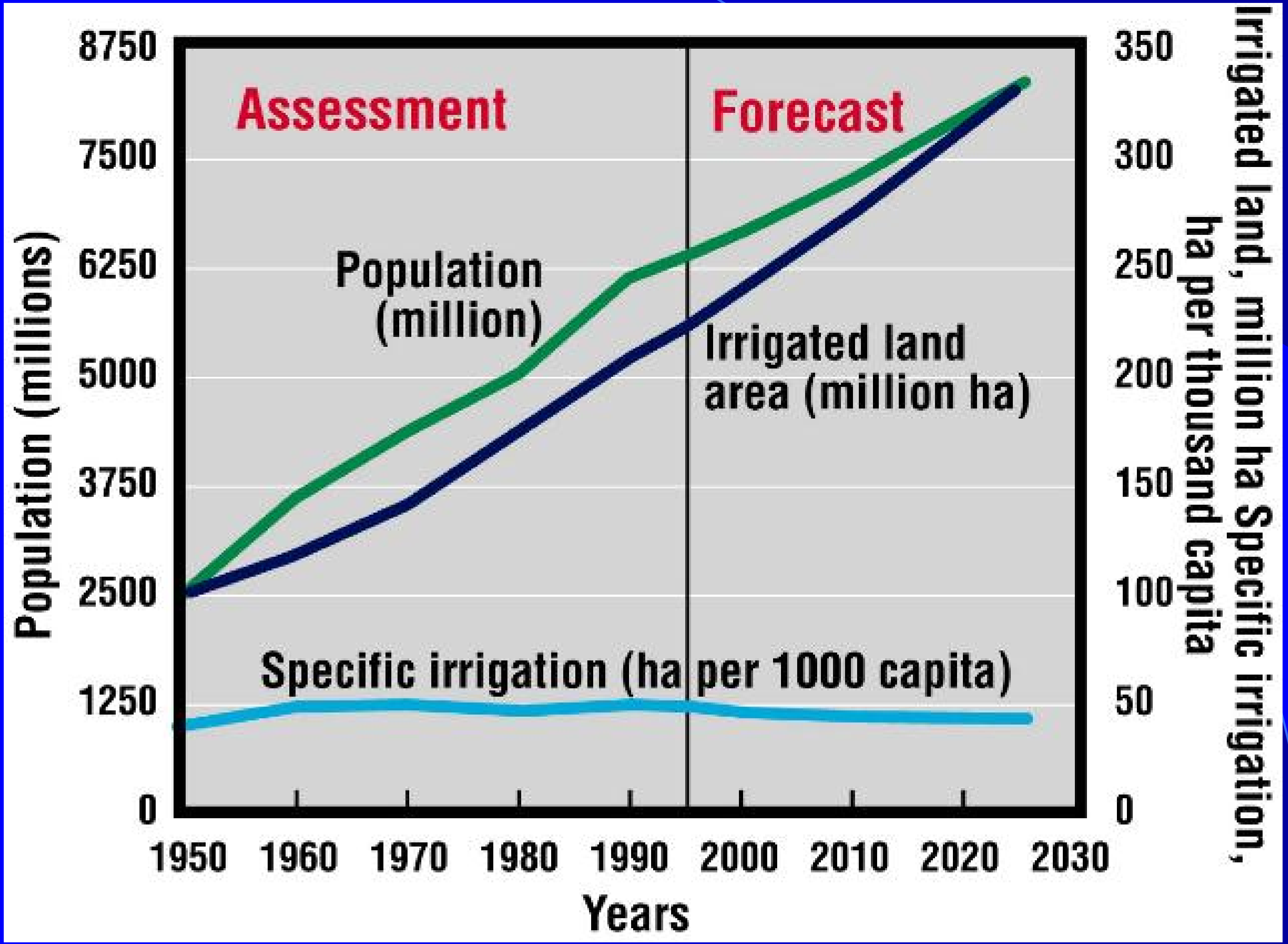
Situation in SE Turkey

- 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

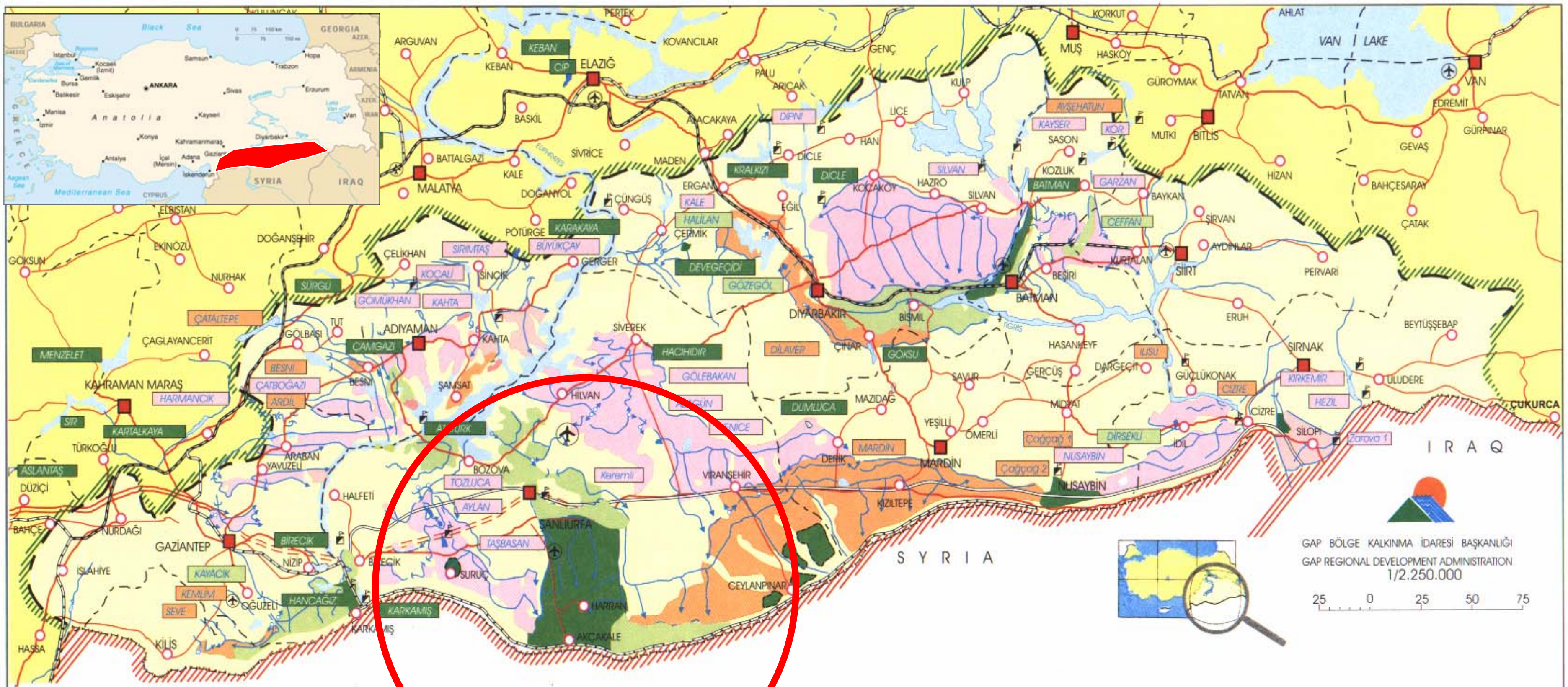


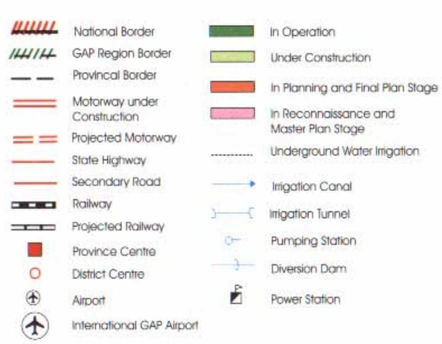
Multidisciplinary Research Project

- 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

GAP WATER RESOURCES PROJECTS





2002

Project	Capacity (MW)	Production (Gwh)	Irrigation Area (Ha)	Present
A. EUPHRATES BASIN	5304	20098	1 091 [illegible]	
I. Karakaya Project	1800	7354		
•Karakaya Dam&HEPP	1800	7354		OP
II. Lower Euphrates Project	2450	[illegible]024	706 281	
• Atatürk Dam&HEPP	[illegible]	8900		OP
• ŞAnlıurfa HEPP	50	124		U/C
• Şanlıurfa Irr. Tunnels				OP+U/C
a)Ş. Urfa-Harran Irr.			118 000	OP
			49 795	U/C
b)Mardin-Ceylanpınar Gravity Irr.			185 639	M/P+U/C
c)MArdin-Ceylanpınar Pumped Irr			149 000	M/P
•Siverek-Hilvan Pumped Irr.			160 105	Rec
•Bozova Pumped Irrigation			69 702	U/C
III. Border Euphrates Project	852	3168		
•Birecik Dam&HEPP	672	2516		OP
•Karkamış Dam&HEPP	180	652		OP
IV.Suruç-Yaylak Project			146 500	
•Yaylak Plain Irr.			18 332	U/C
•Suruç Plain Irr.			128 128	Rec
V.Adıyaman -Kahta Project	195	509	77 824	
•Çamgaz Dam&Irr.			6 536	OP
•Gömikhan Dam&Irr.			7 762	M/P
•Koçali Dam&HEPP	40	120	21 605	M/P
•Sırımtaş Dam&HEPP	28	87		M/P
•Fatopaşa HEPP	22	47		M/P
•Büyükçay Dam HEPP&Irr.	30	84	12 322	M/P
•Kahta Dam&HEPP	75	171		M/P
•Pumped Irr From Ataturk Reservoir			29 599	M/P+U/C

Project	Capacity (MW)	Production (Gwh)	Irrigation Area (Ha)	Present
VI. Adıyaman-Göksu	7	43	71 598	M/P
•Çataltepe Dam&Irr.			71 598	M/P
Erkenek HEPP	7	43		M/P
VII.Gaziantep Project			89 000	
•Hancağız Dam&Irr.			7 330	OP
•Kayacık Dam&Irr.			13 680	U/C
•Kemlin Dam&Irr.			1 969	M/P
•Pumped Irr.From Birecik Reservoir			53 415	M/P
•Belkis-Nizip Irr.			11 925	U/C
INDIVIDUAL PROJECTS	144	42	66 795	
Nusaybin Irr.			7 500	OP
Çağ çağ HEPP	144	42		OP
Akçakale Groundwater Irr.			15 000	OP
Ceylanpınar Groundwater Irr.			27 000	OP
Hacıhıdır Project			2 080	OP
Dumluca Project			1 860	OP
Suruç Grounwater			7 000	OP
Besni Dam&Irr.			2 820	M/P
Ardil Dam&Irr.			3 535	M/P
B. TIGRIS BASIN	2 172	7 247	601 824	
VIII.Tigriz-Kıralkızı Project	204	444	126 080	
•Kıralkızı Dam&HEPP	94	146		OP
•Tigris Dam&HEPP	110	298		OP
•Tigris Right Bank Gravity Irr.			54 279	U/C
•Tigris Right Bank Pumped Irr.			71 801	U/C
IX.Batman Project	198	483	37 744	
•Batman Dam&HEPP	198	483		OP
•Batman Left Batman bank Irr.			18 758	U/C
•Batman Right Bank Gravity Irr.			18 986	U/C

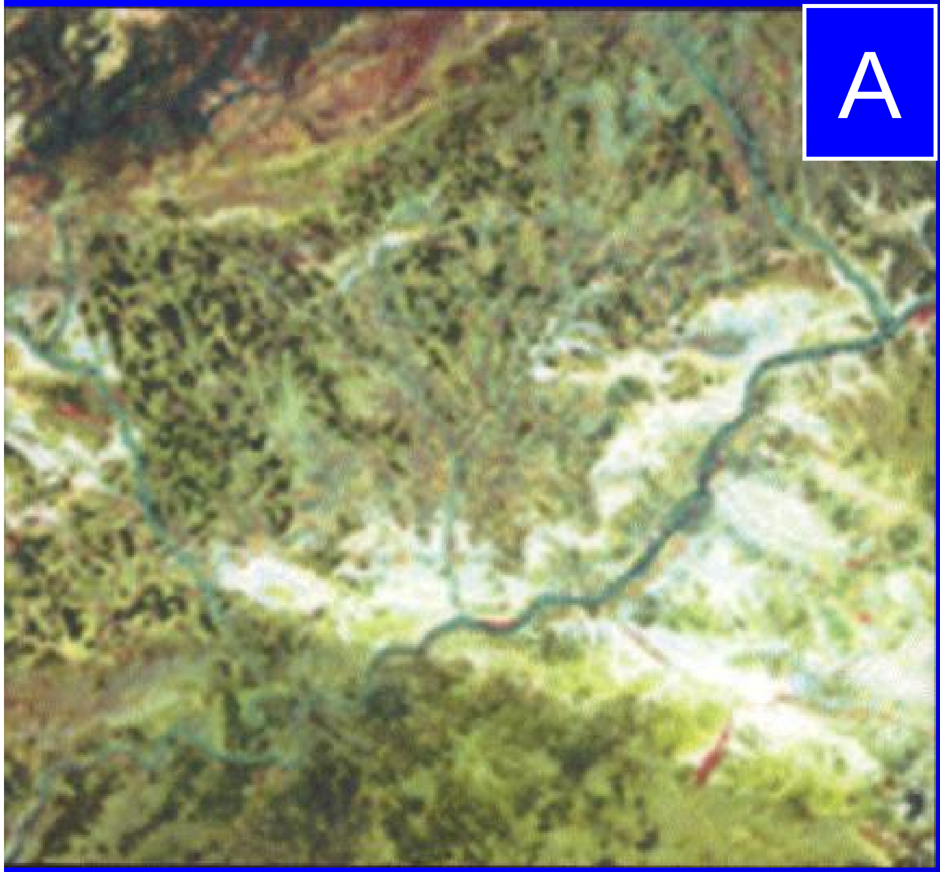
Project	Capacity (MW)	Production (Gwh)	Irrigation Area (Ha)	Present
X.Batman-Silvan Project	240	964	257 000	
•Silvan Dam&HEPP	150	623		Rec
•Kayser Dam&HEPP	90	341		Rec
•Tigris left Bank Gravity Irr.			200 000	Rec
•Tigris left Bank Pumped Irr.			57 000	Rec
XI.Garzan Project	90	315	60 000	
•Garzan Dam&HEPP	90	315		Rec
•Garzan Irr.				
	1200	3 833		
XII.Ilısu Project	1200	3 833		D/D
•Ilısu Dam&HEPP				
	240	1 208	121 000	
XIII.Cizre Project	240	1 208		Imp
•Cizre Dam&HEPP			89 000	Rec
•Nusaybin-Cizre Irr.			32 000	Rec
•Silopi Irr.				
INDIVIDUAL PROJECTS			26 312	
Devegeçiti Project			7 500	OP
Silvan I&II Irr.			8 790	OP
Nerdüş Irr.			2 740	OP
Çınar Göksu Project			3 582	OP
Garzan-Kozluk Irr.			3 700	OP

Note: Individual projects are not included in grand total

Legend: OP -In Operation
U/C -Under Construction
D/D -Detailed Design Completed
F/S - Feasibility study
M/P - Master Plan
Rec Reconnaissance
Imp- On Implementation Program

Source: 1. General Command of Maping 1/500.000 Scale Maps
2. General Directorate of State Hydraulic Works (DSI) 31.12.1999

Atatürk Dam and Reservoir



1975

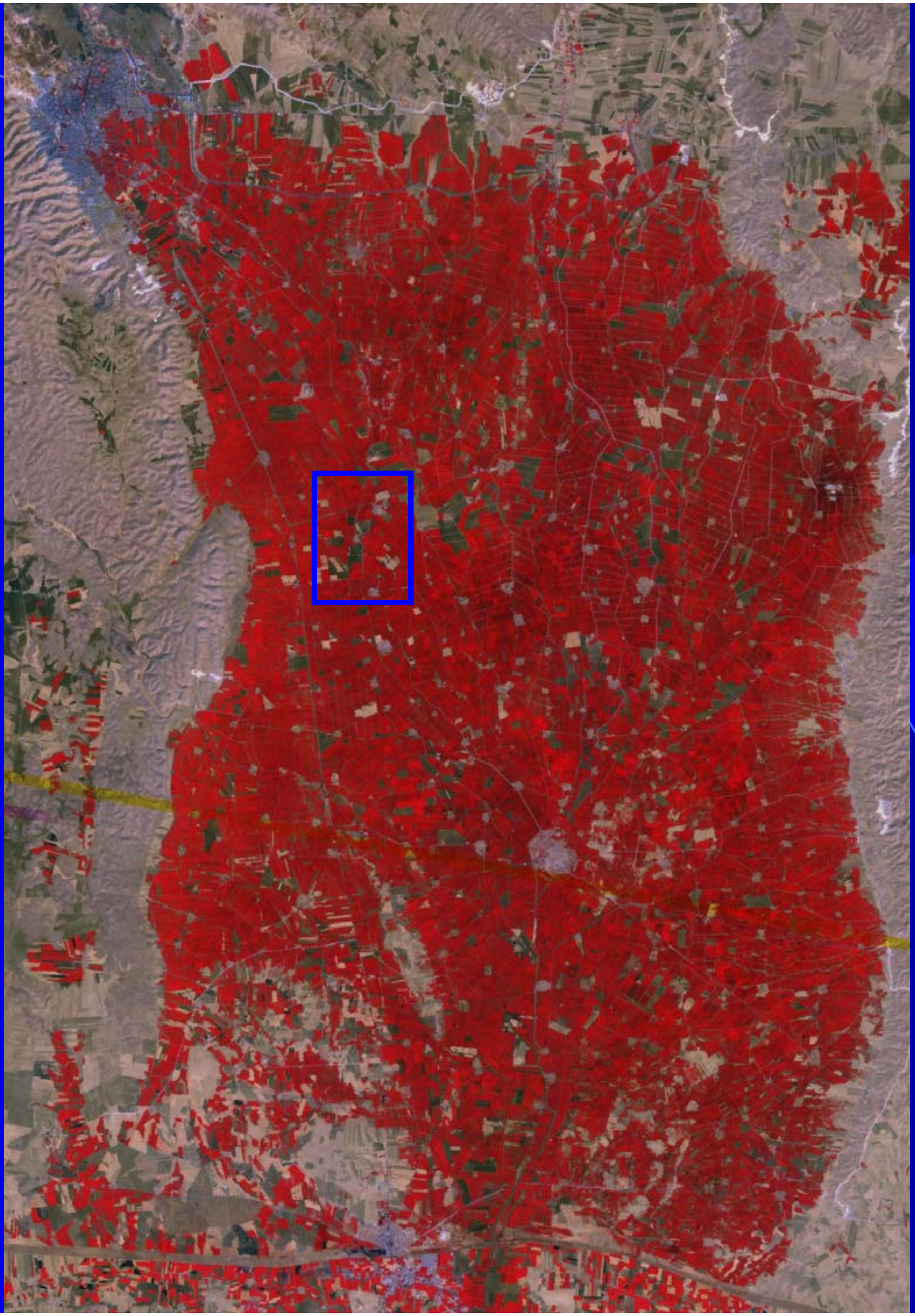
1999


D S İ
6/16/2002 07:16


6/15/2002 07:02

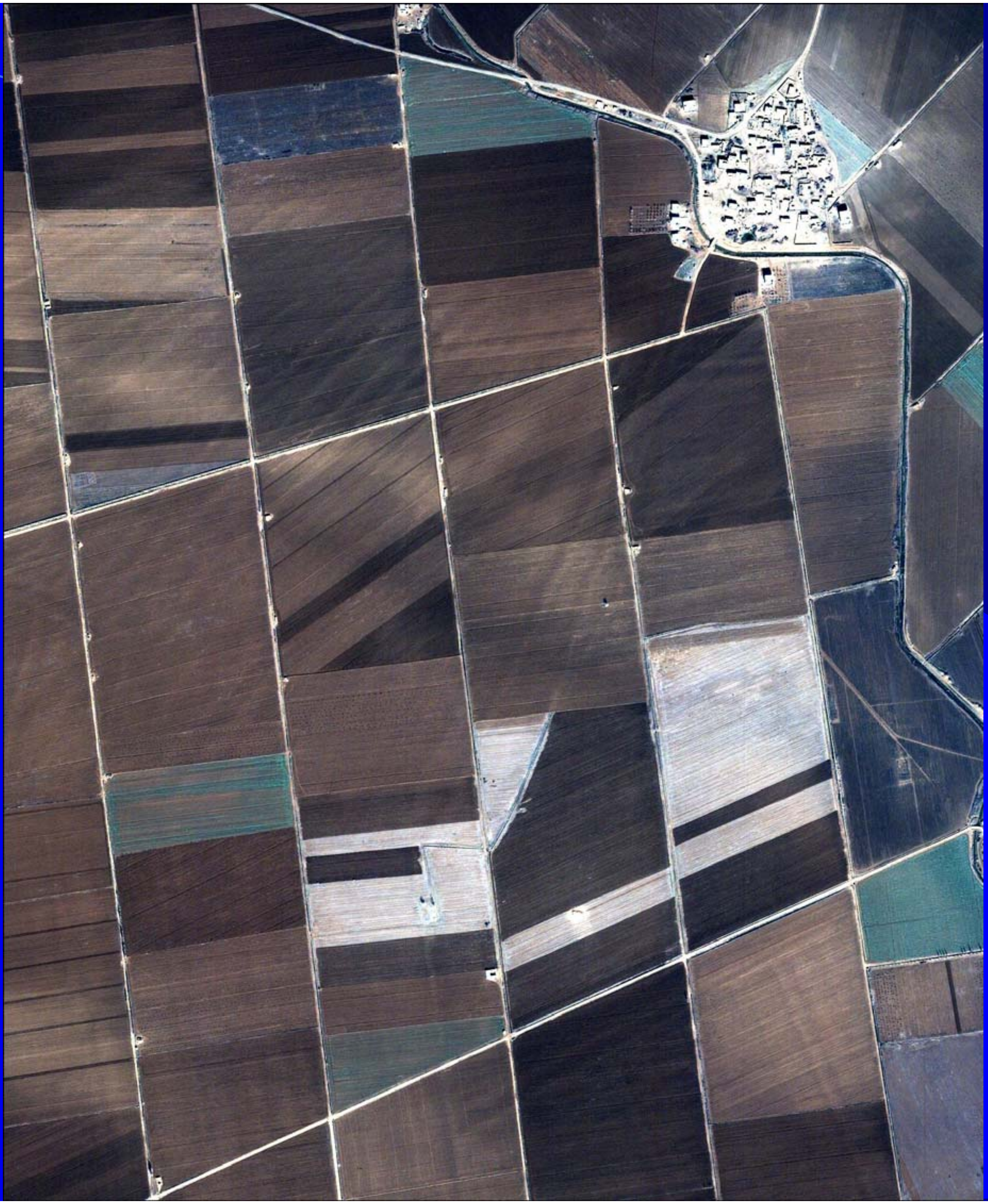
ETM+ image

September 1, 1999

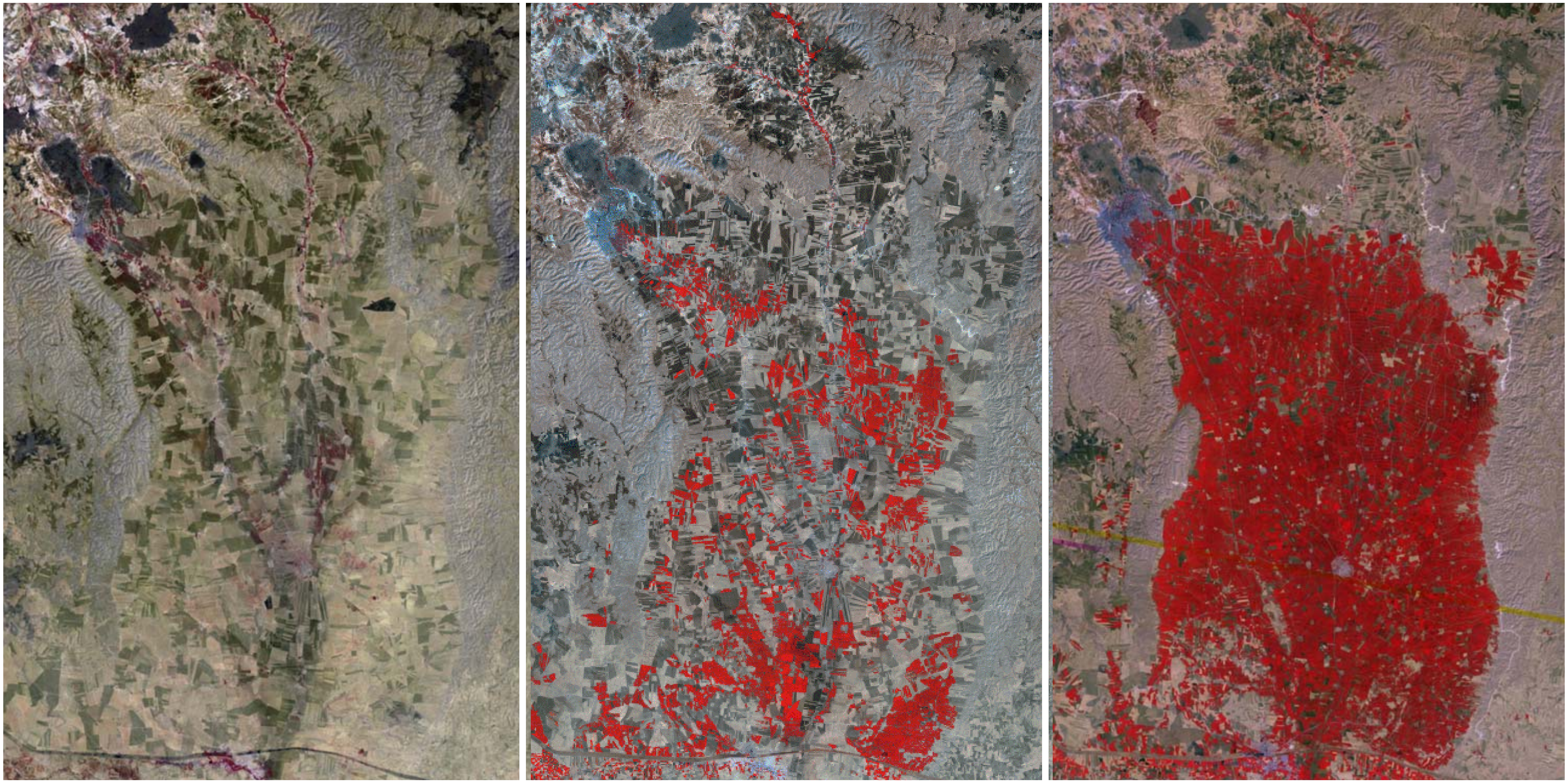


IKONOS image

December, 2000



Harran Plain



1978 1992 1999

All late-summer images

Results (Remote Sensing of Irrigation)

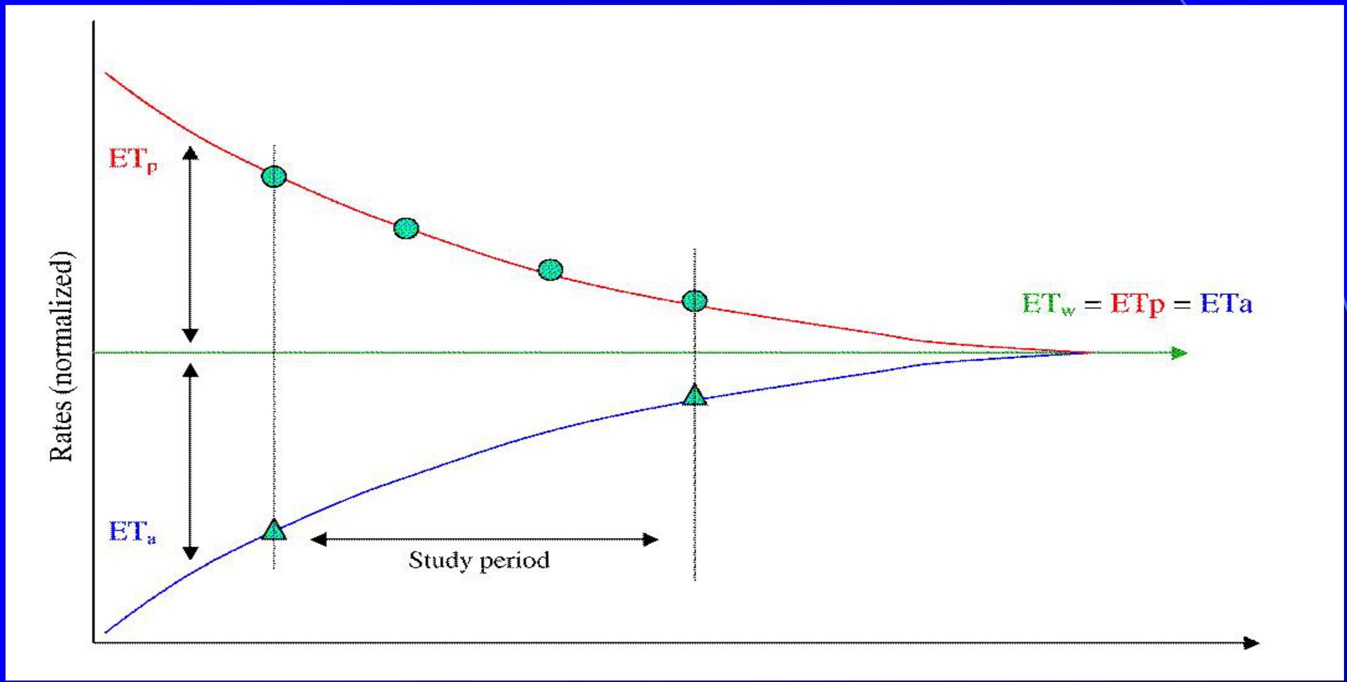
- Between 1980 and 2002 irrigated area has increased ~2000 percent
- Similar increase in agricultural water use
- 1.18 bcm in 2002 (~3% of total Euphrates flow)
- MODIS data useful for optimum timing
- NDVI thresholding method is reliable
- Applicable in other areas with single crop

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

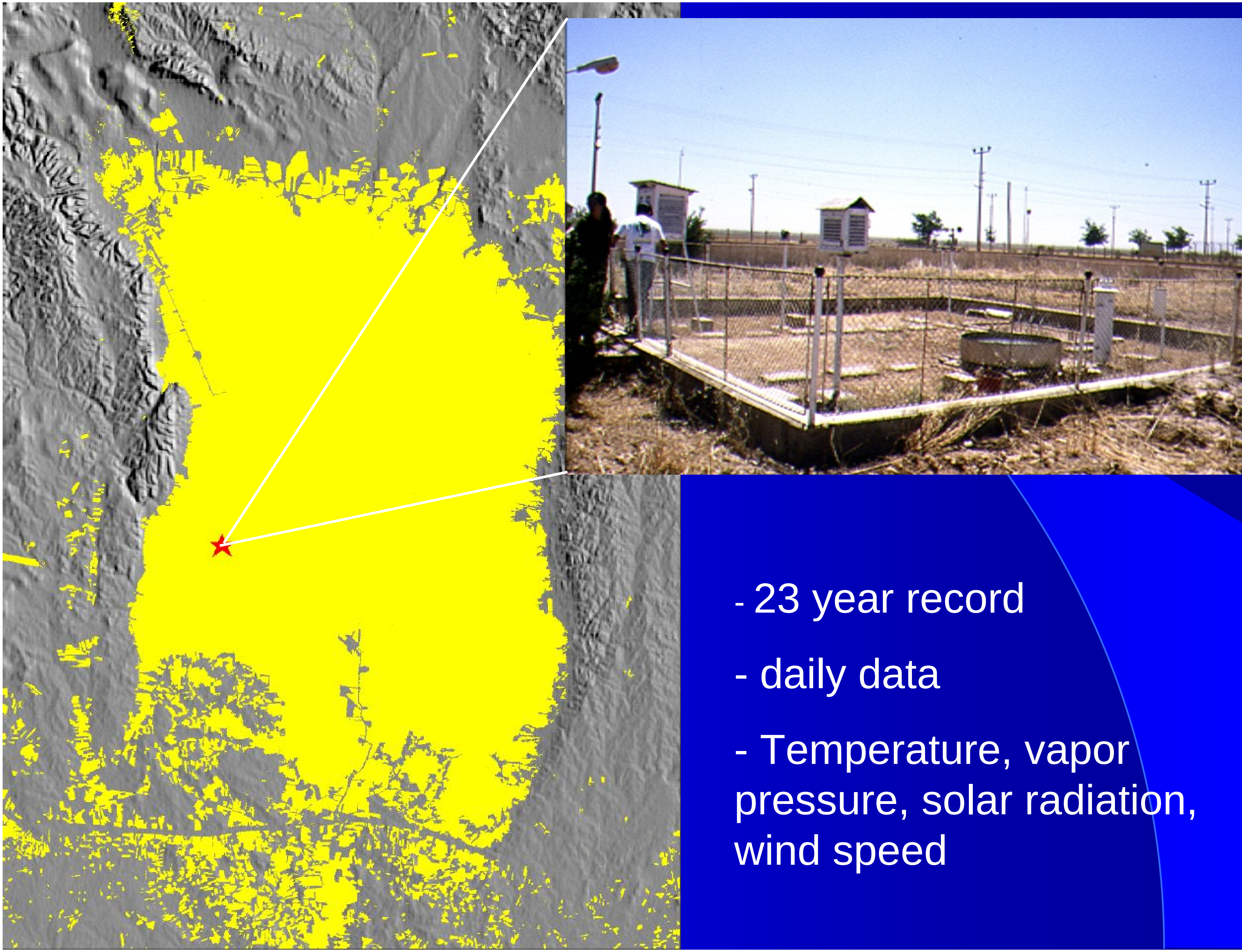
Complementary Relationship (CR)

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

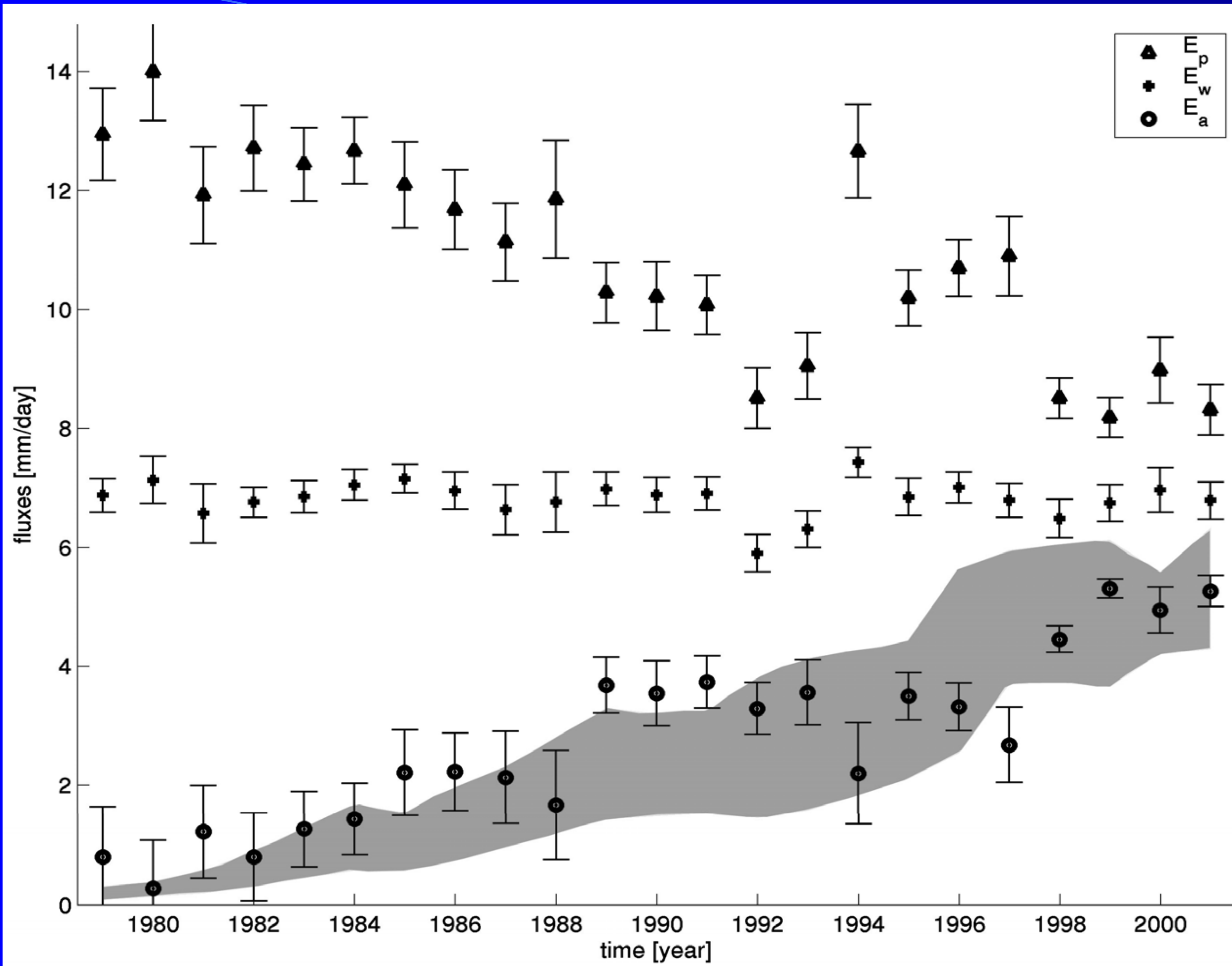


Evaporation Definitions

- ***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 evporation from moist surfaces (it is rarely achieved)



- 23 year record
- daily data
- Temperature, vapor pressure, solar radiation, wind speed



14
12
10
8
6
4
2
0
fluxes [mm/day]
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
time [year]
E_p
E_w
E_a

CR Results (neutral case)

- E_P decreased ~15 mm/day to ~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 ~ 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