# Soil Moisture Measurements and Water Availability Index Derivation Using Remote Sensing Images

**presented by**

**Dr. Ni-Bin Chang**

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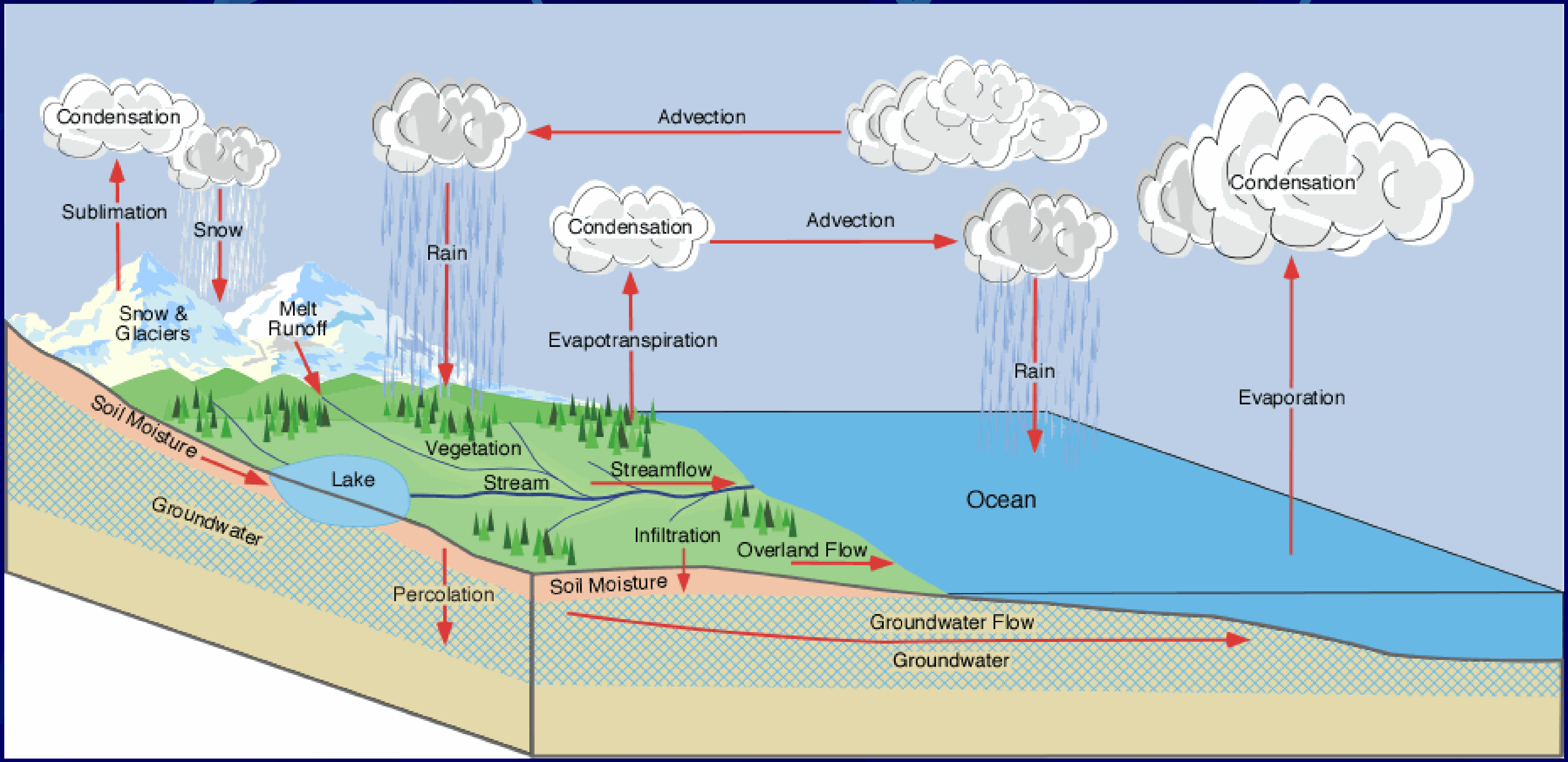
# Why do we need to care about soil moisture?



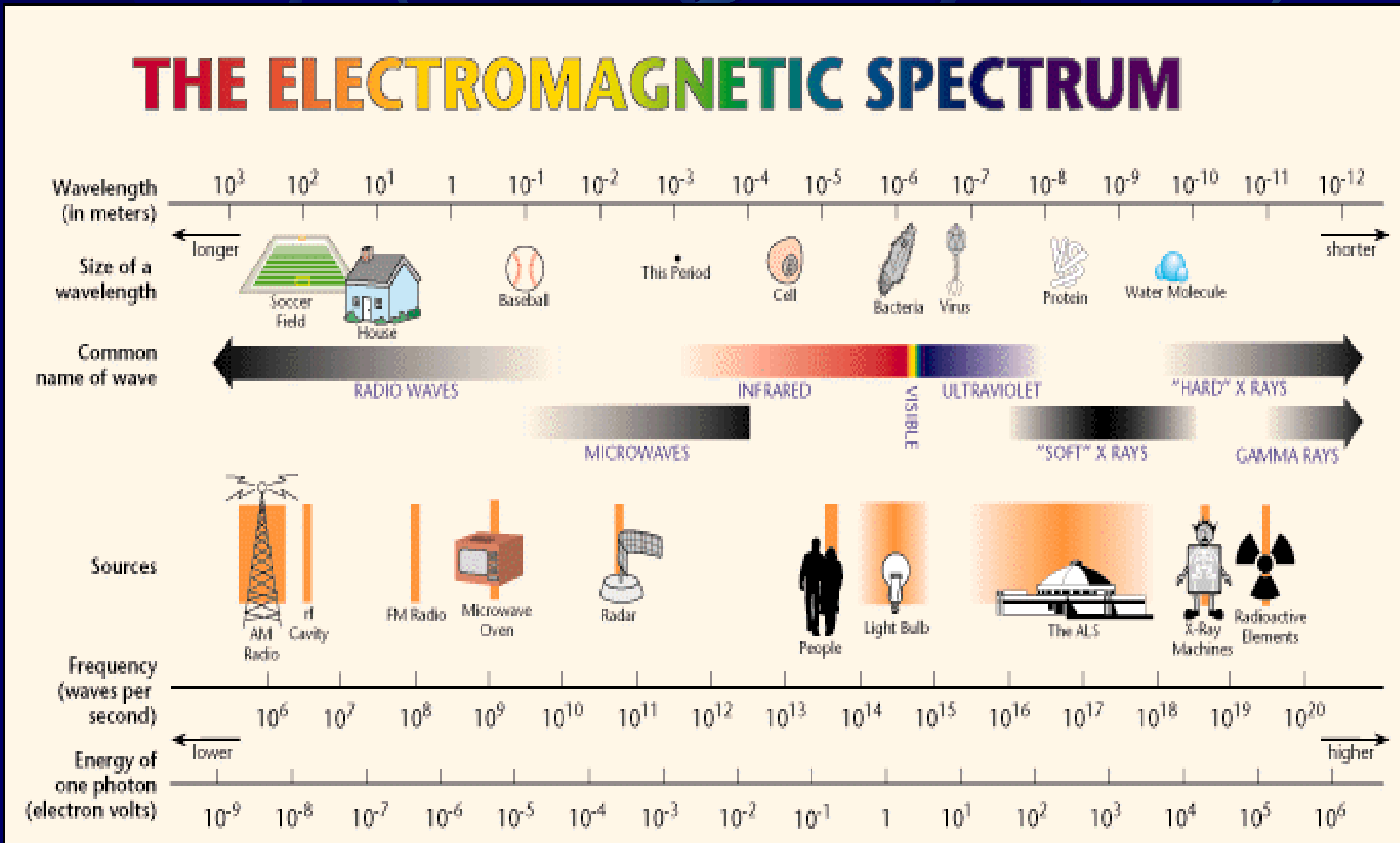

Hydrological Cycle

# Outline of Presentation

- Study Objectives
- Rationale of Remote Sensing for Soil Moisture Measurements
- Study Area: Watershed Environment
- Field Efforts: Satellite Image Acquisition and Ground Truthing
- Modeling Process and Soil Moisture Mapping
- Future Work

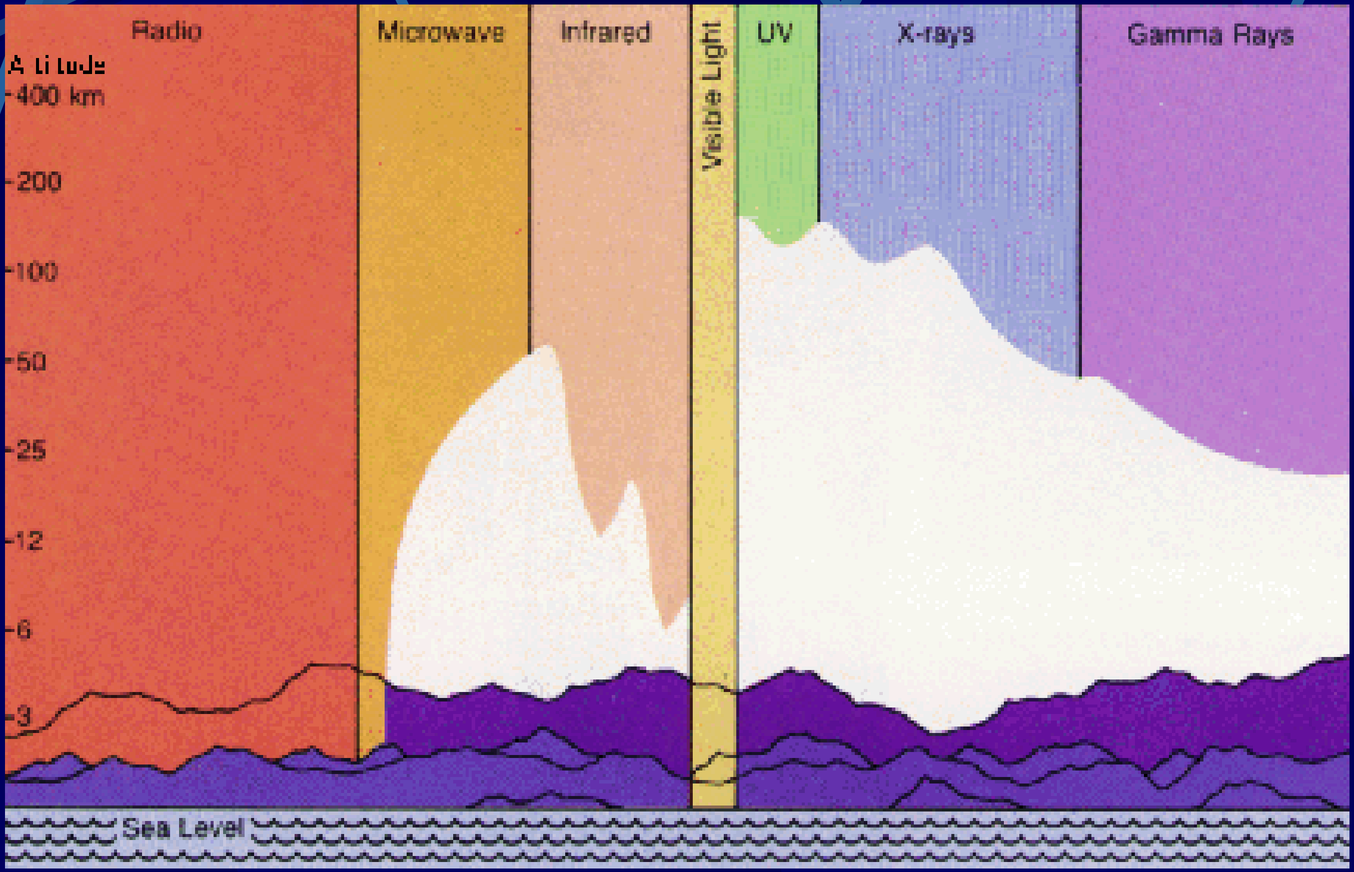
# Study Objectives

- Understand the rationale of space borne remote sensing for soil moisture measurement
- Validate microwave soil moisture retrieval algorithms for an existing microwave sensor systems: RADARSAT-1.
- Integrate satellite remote sensing with genetic programming model to predict the soil moisture distribution in a semi-arid watershed.



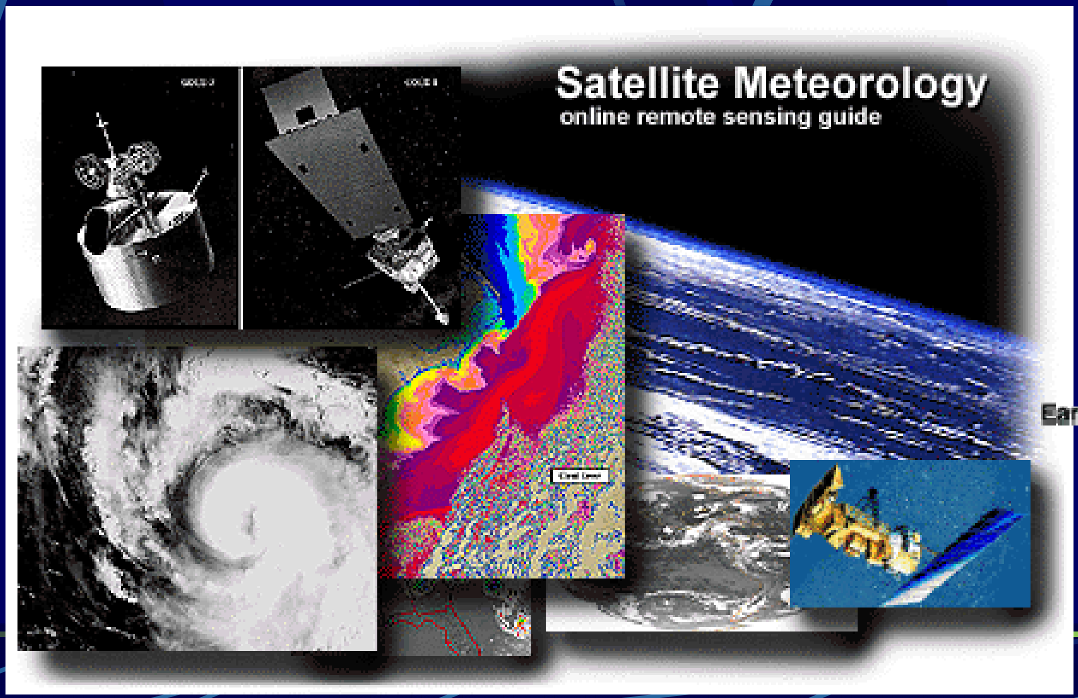
THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10³ 10² 10¹ 1 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶ 10⁻⁷ 10⁻⁸ 10⁻⁹ 10⁻¹⁰ 10⁻¹¹ 10⁻¹²
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰ 10¹¹ 10¹² 10¹³ 10¹⁴ 10¹⁵ 10¹⁶ 10¹⁷ 10¹⁸ 10¹⁹ 10²⁰
lower
higher
Energy of one photon (electron volts)
10⁻⁹ 10⁻⁸ 10⁻⁷ 10⁻⁶ 10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 1 10¹ 10² 10³ 10⁴ 10⁵ 10⁶

# Electromagnetic Spectrum



# Satellite Hydrology

- Geostationary Operational Environmental Satellites (GOES)
- Polar Orbiting Environmental Satellites (POES).

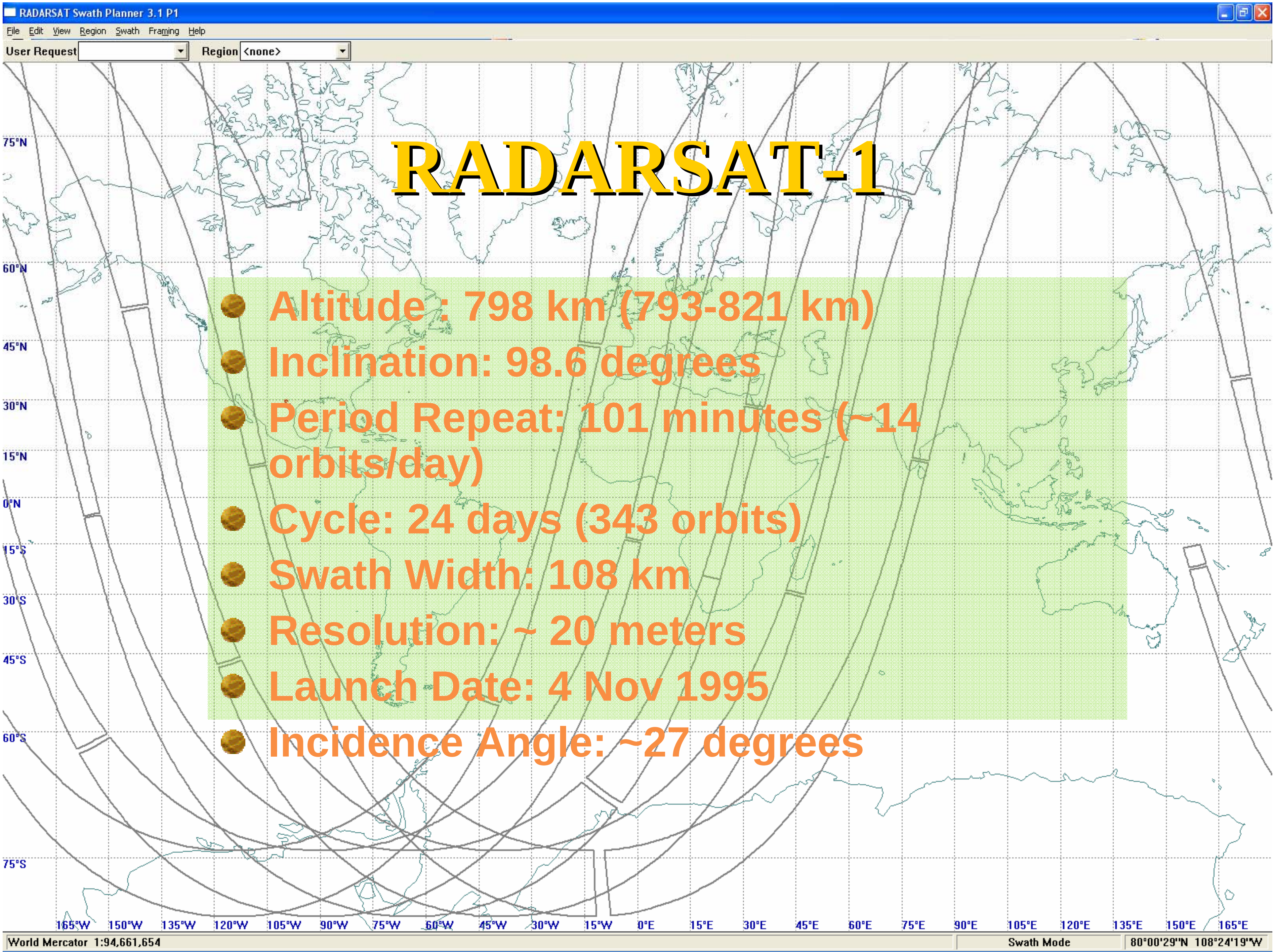



# Remote Sensing for Soil Moisture Measurement

- **Active measurement: A microwave pulse (radar) is sent and the power of received signal is compared to that which was sent to determine the backscattering coefficient.**
- **Passive measurement: Natural thermal emission of land surface (or brightness temperature) is measured at microwave frequencies.**

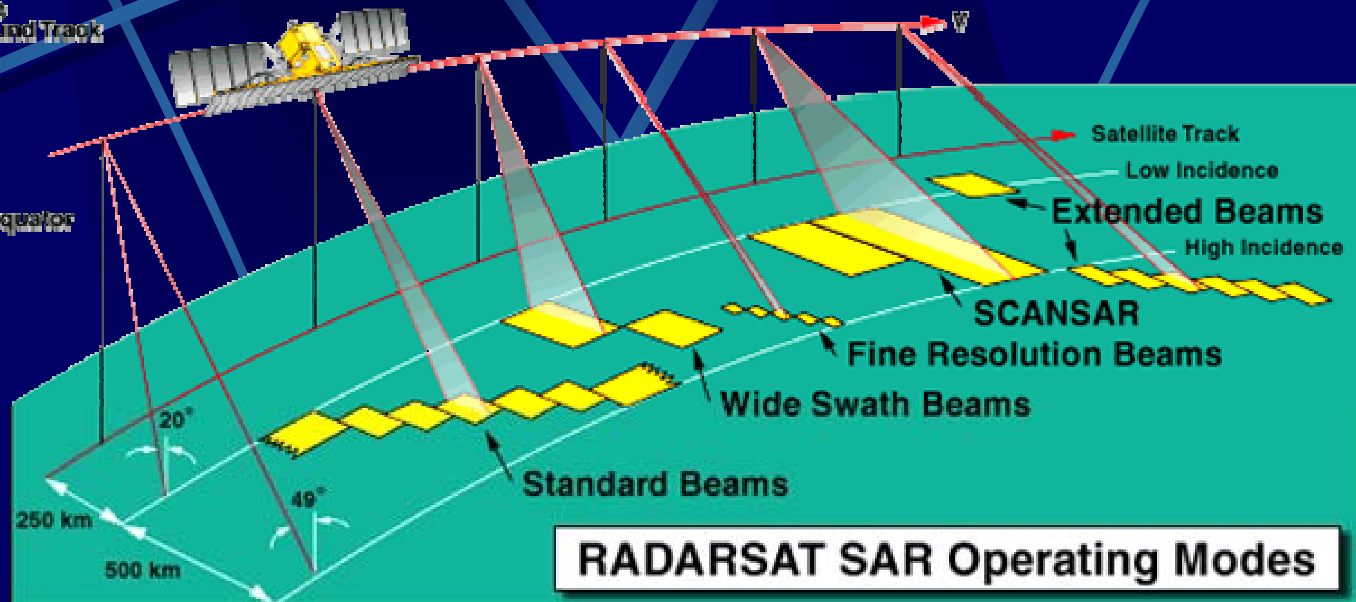
# RADARSAT-1

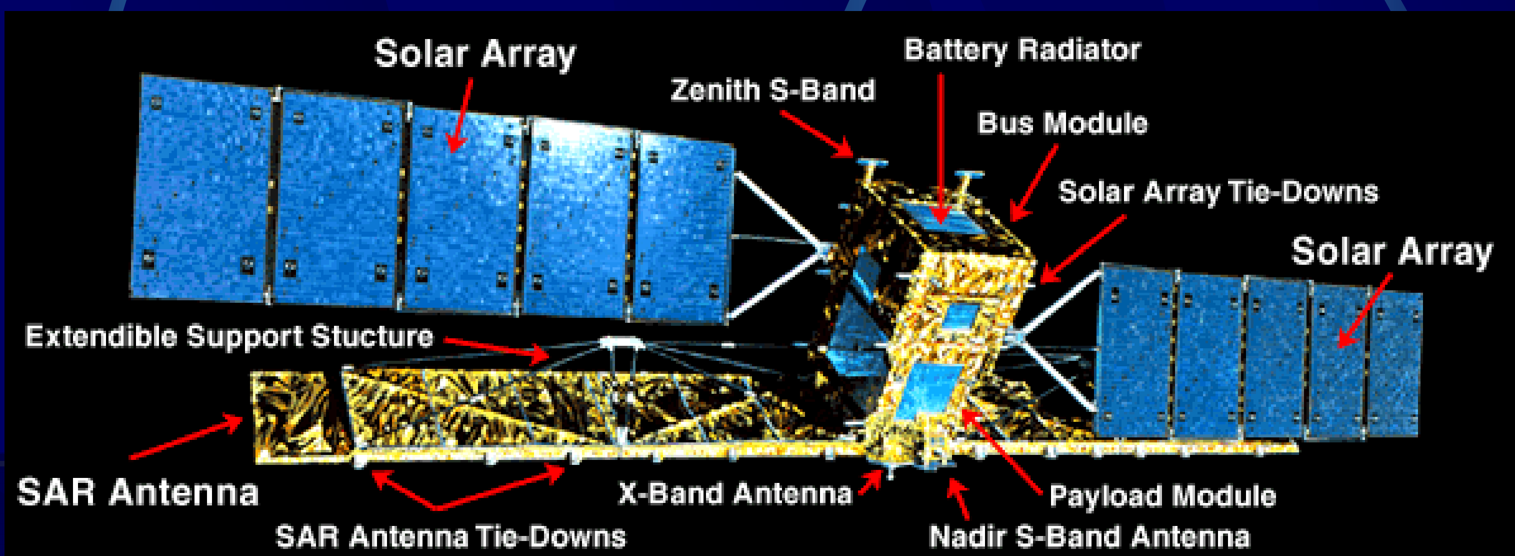
- Altitude : 798 km (793-821 km)
- Inclination: 98.6 degrees
- Period Repeat: 101 minutes (~14 orbits/day)
- Cycle: 24 days (343 orbits)
- Swath Width: 108 km
- Resolution: ~ 20 meters
- Launch Date: 4 Nov 1995
- Incidence Angle: ~27 degrees



# RADARSAT-1

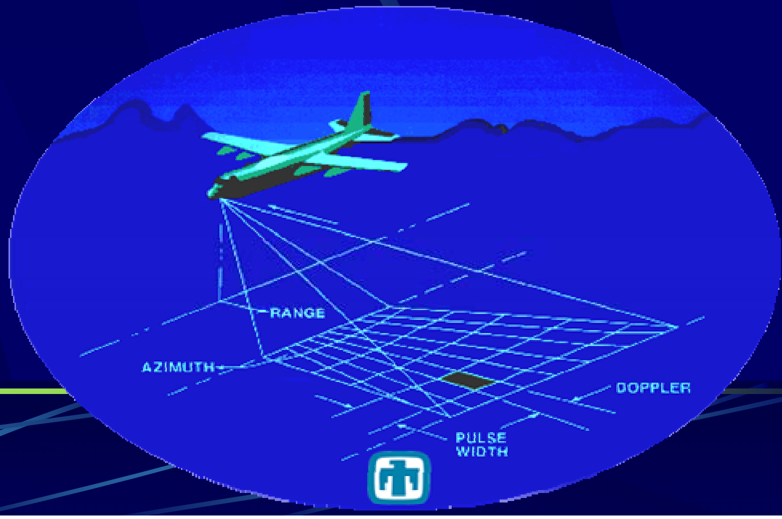

Satellite Ground Track
Equator


V
Satellite Track
Low Incidence
Extended Beams
High Incidence
SCANSAR
Fine Resolution Beams
Wide Swath Beams
Standard Beams
20°
49°
250 km
500 km
RADARSAT SAR Operating Modes


Solar Array
Zenith S-Band
Battery Radiator
Bus Module
Solar Array Tie-Downs
Solar Array
Extendible Support Stucture
SAR Antenna
SAR Antenna Tie-Downs
X-Band Antenna
Payload Module
Nadir S-Band Antenna

# Synthetic Aperture Radar

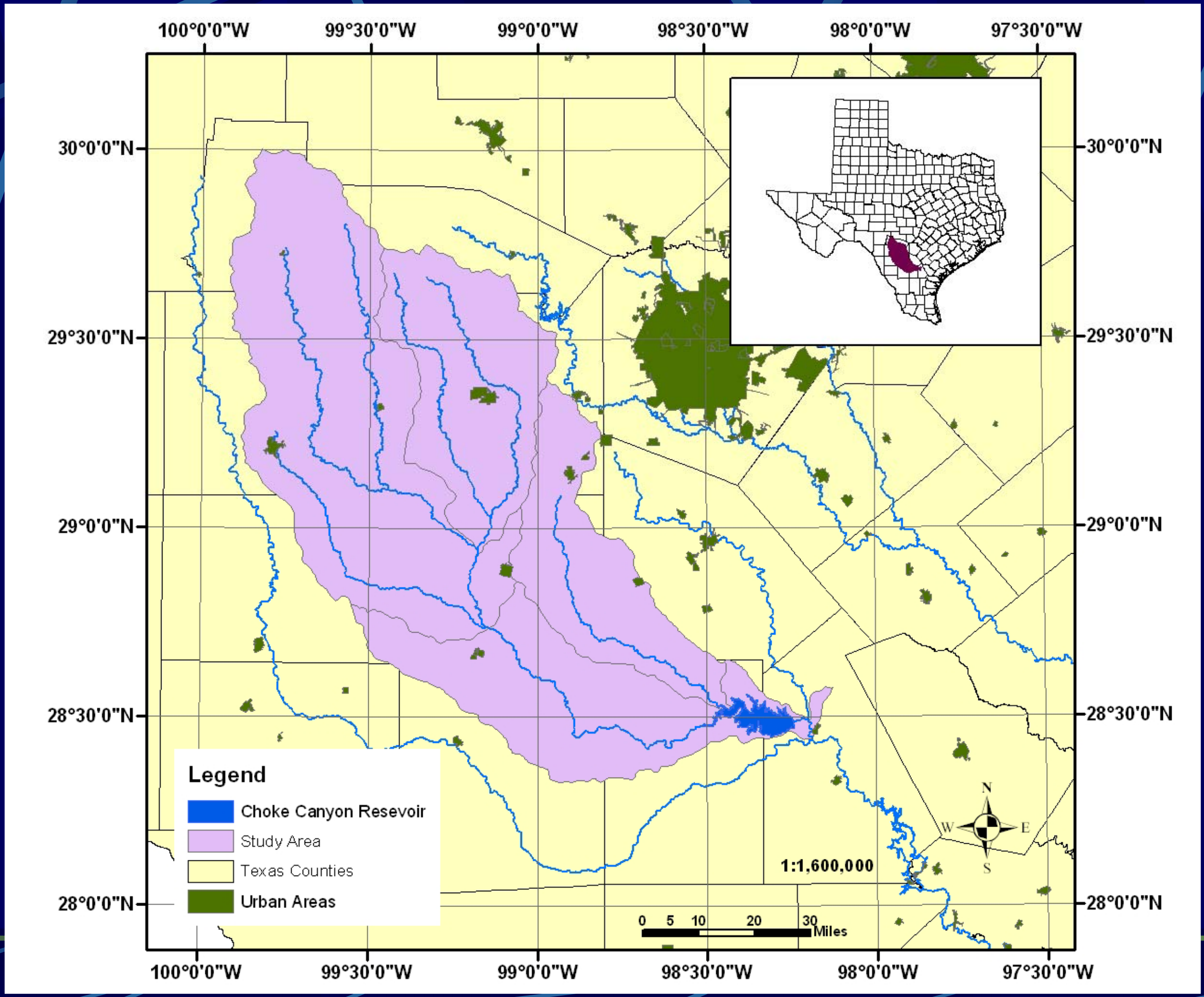
- SAR systems take advantage of
  - the long-range propagation characteristics of radar signals and
  - the complex information processing capability of modern digital electronics to provide high resolution imagery.



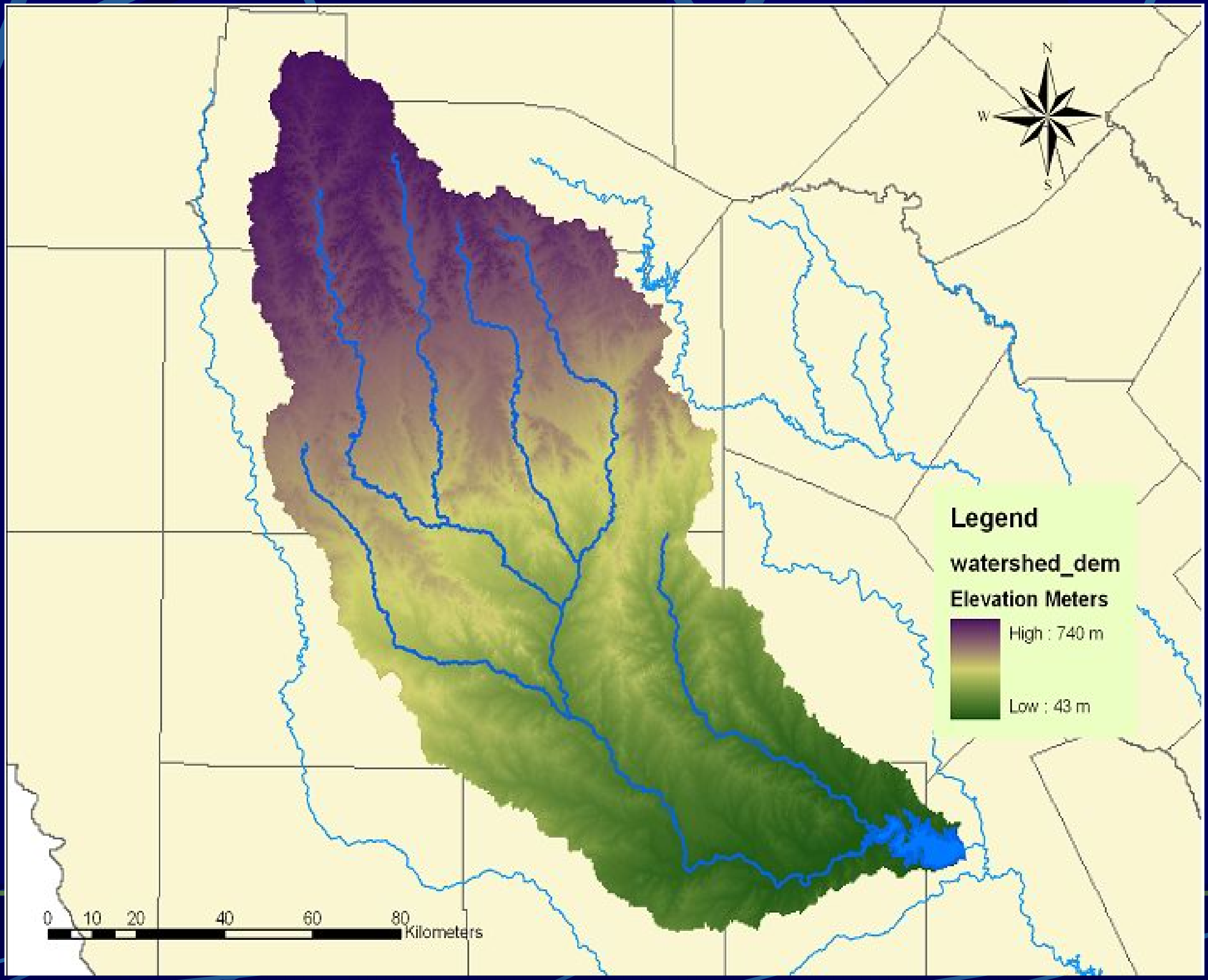
# RADASAT-1 SAR Satellite

- When using a space-borne SAR satellite with active microwave sensor, the radar backscatter is sensitive to:
  - Water content in the surface soil
  - Surface roughness and vegetation cover
  - Angle of incidence
  - Surface slope
- This exhibits a potential to measure surface soil moisture

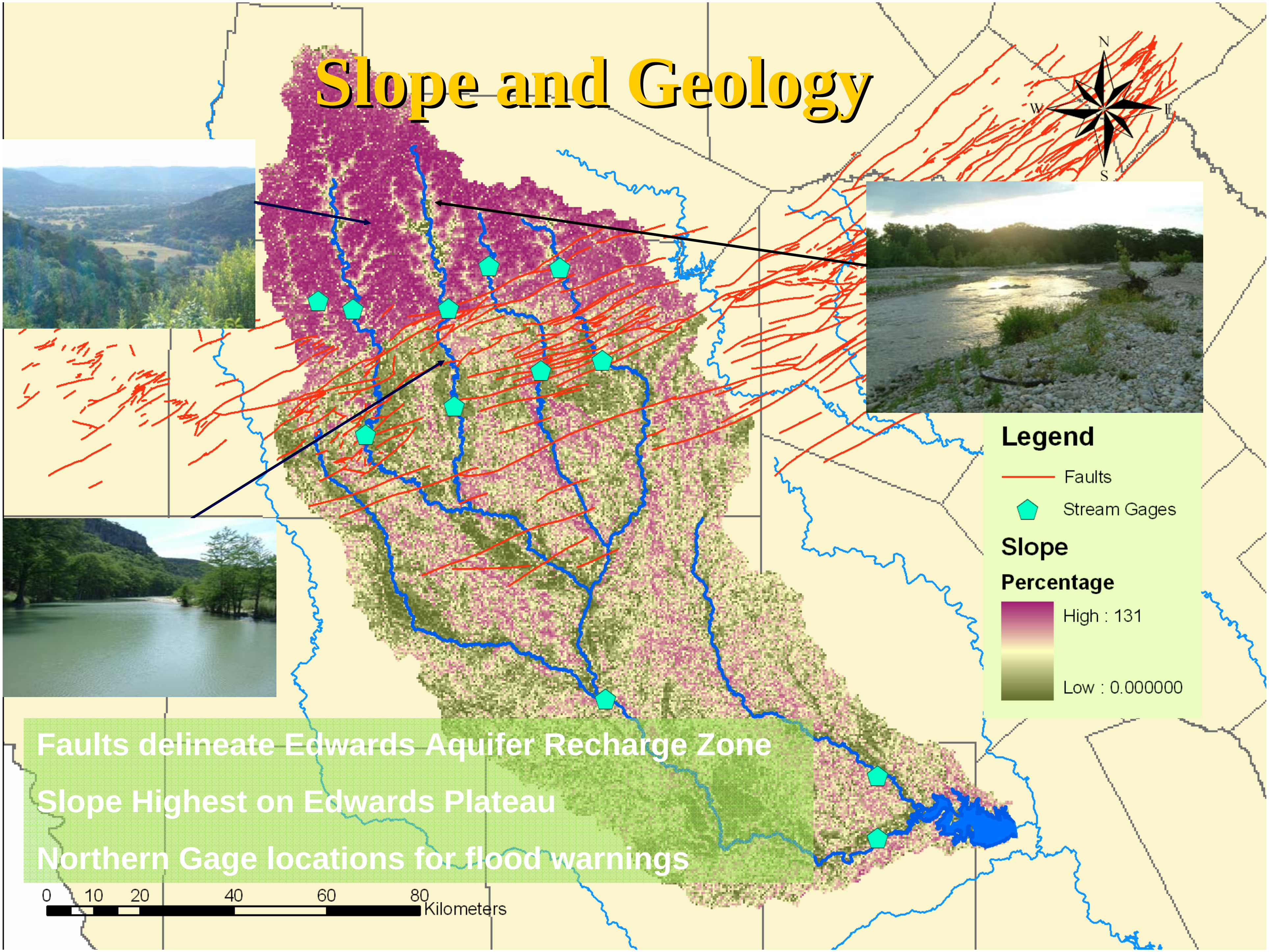
# Study Area: Choke Canyon Reservoir Watershed, South Texas



# Differences of Elevation from 740 m to 40 m



# Slope and Geology

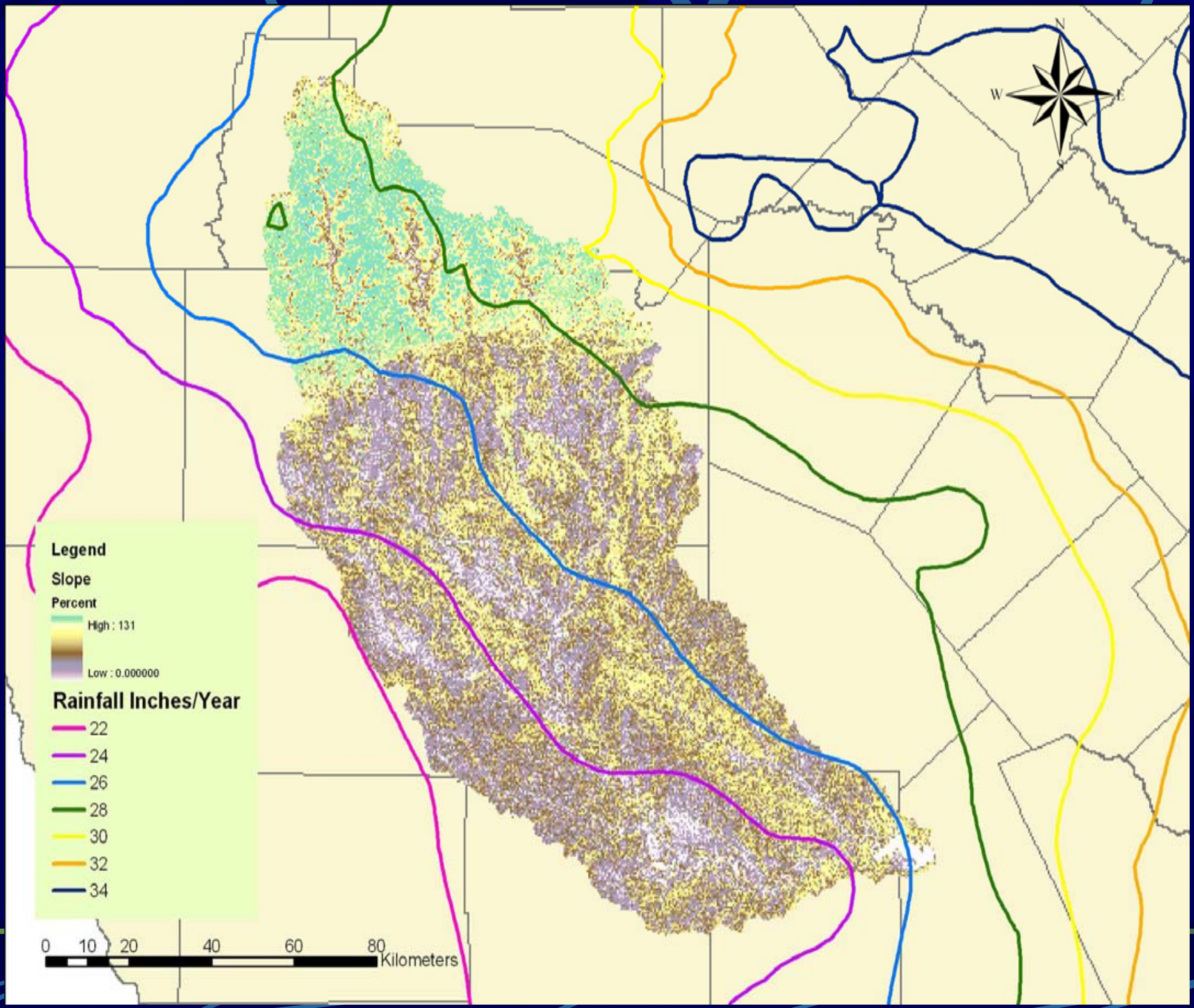



Faults delineate Edwards Aquifer Recharge Zone

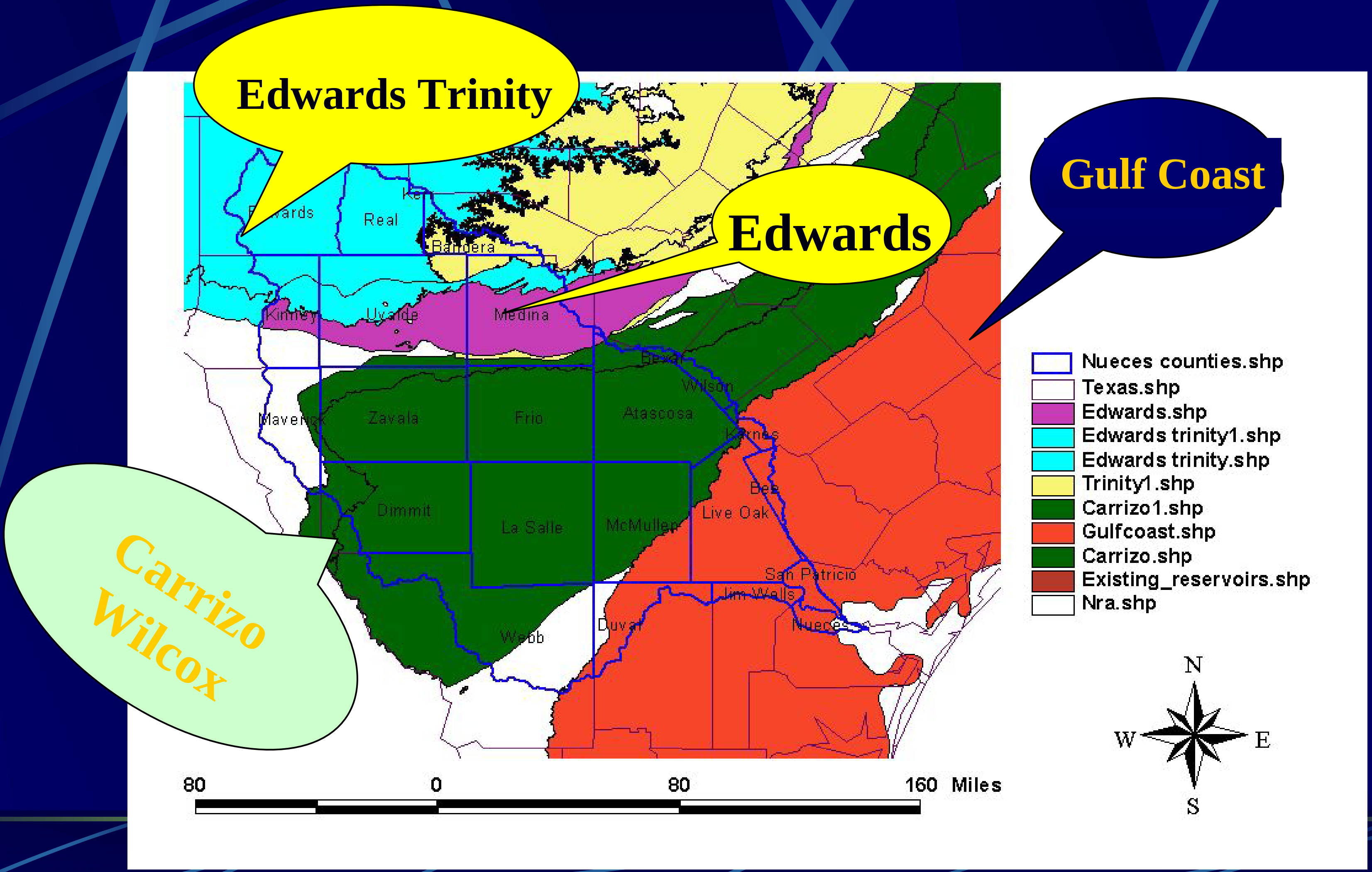
Slope Highest on Edwards Plateau

Northern Gage locations for flood warnings

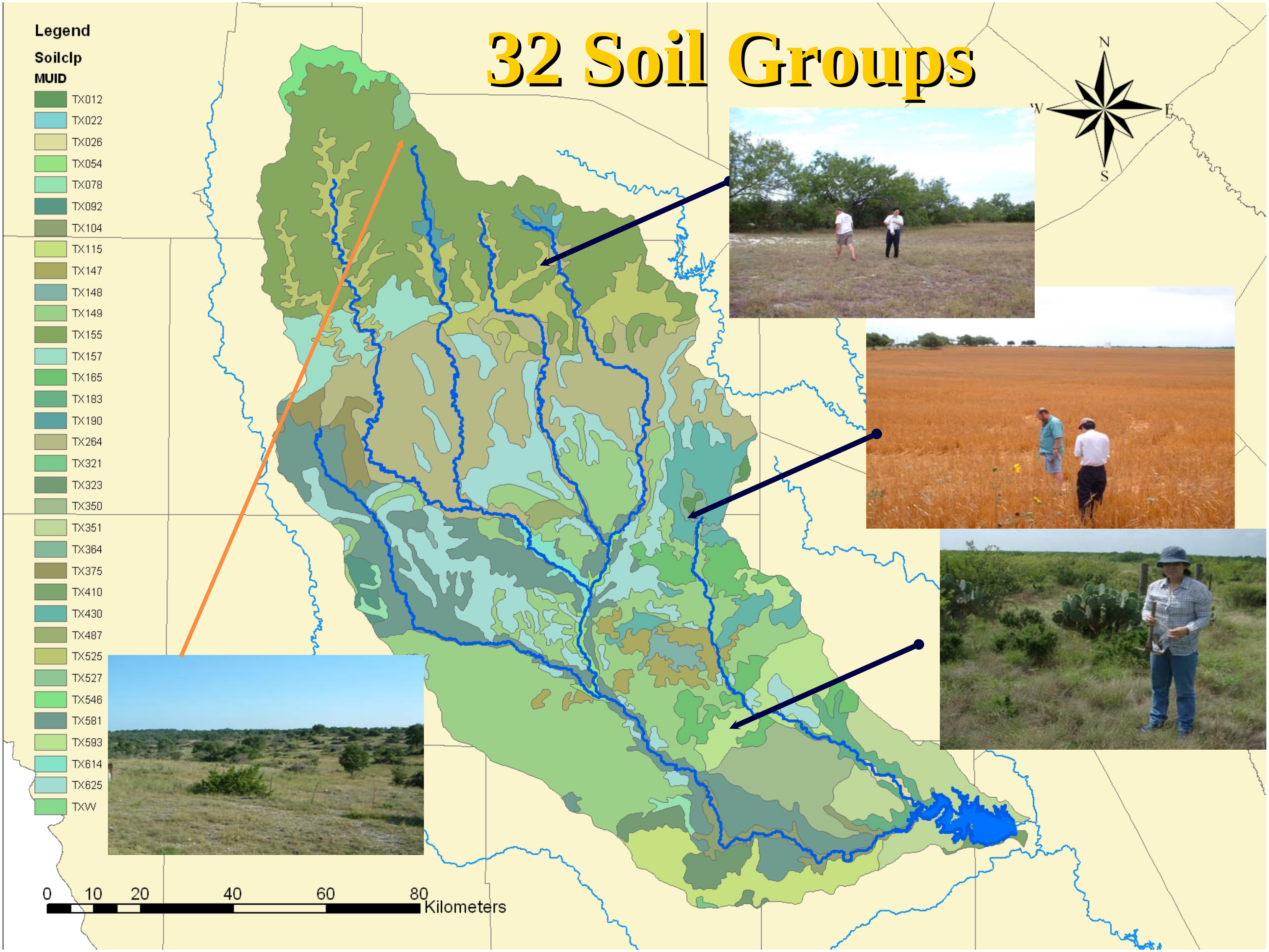
# Annual Rainfall (inch per year)



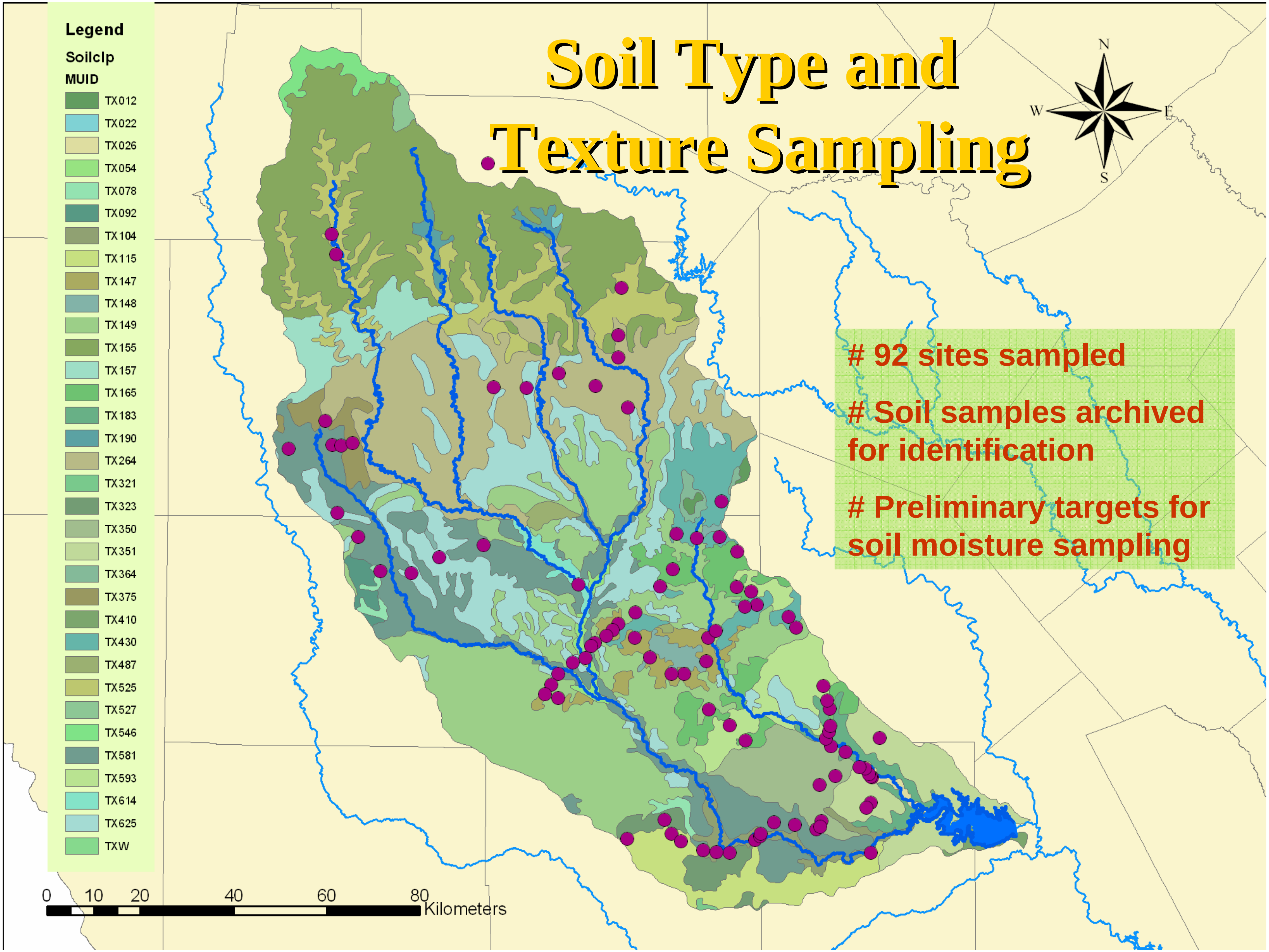
# Nueces River Basin Aquifers



# 32 Soil Groups



# Soil Type and Texture Sampling

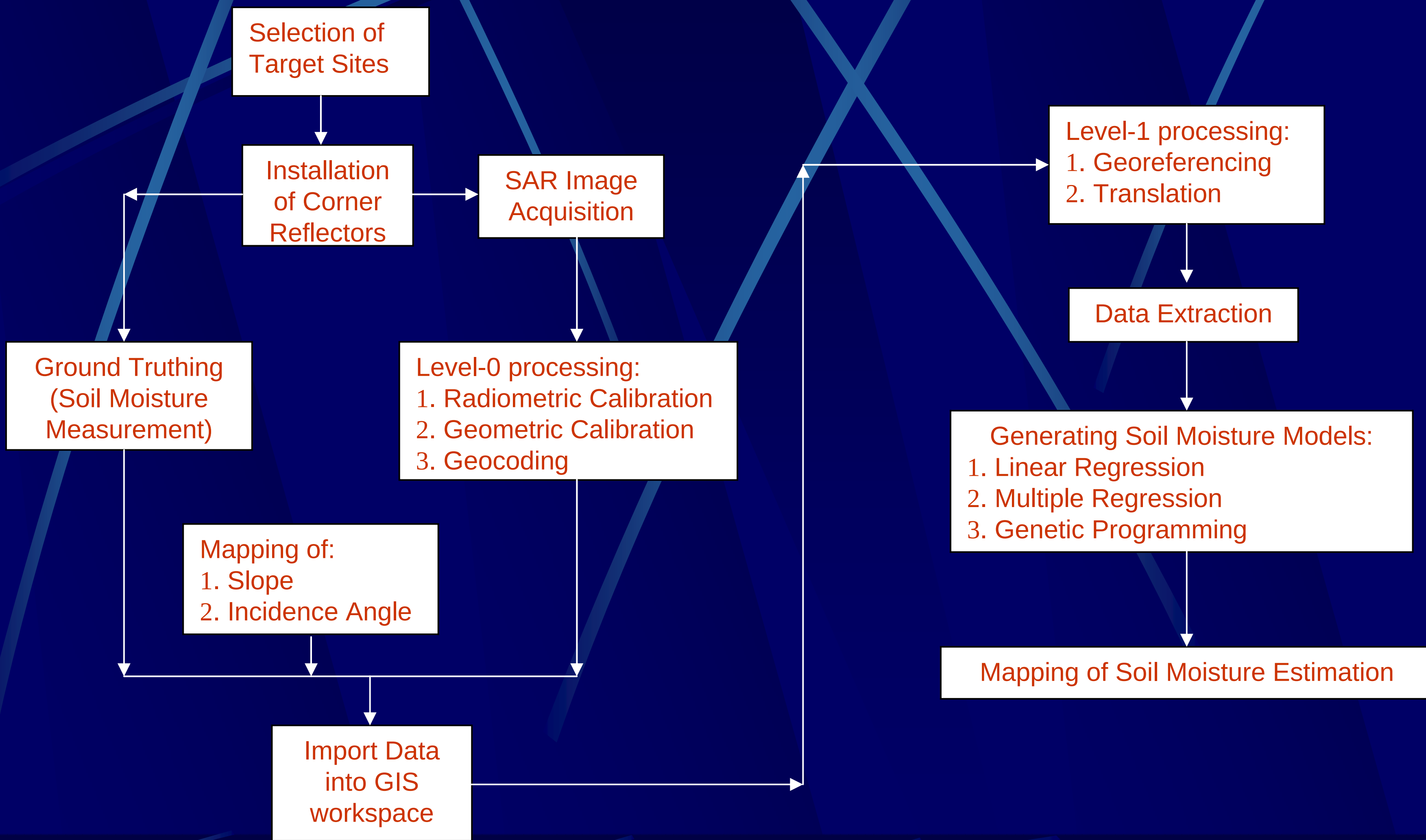


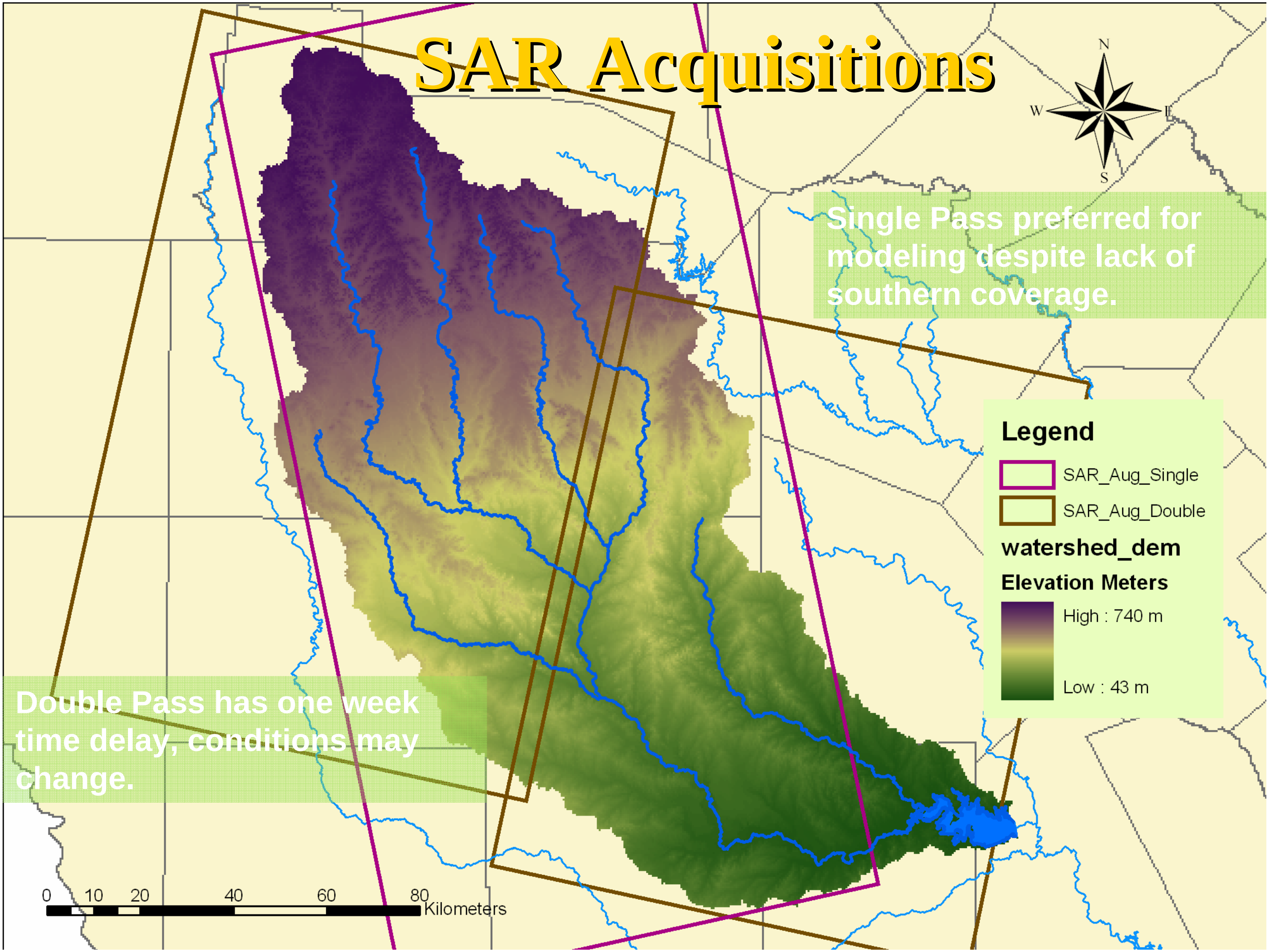

# 92 sites sampled

# Soil samples archived for identification

# Preliminary targets for soil moisture sampling

# Flow Chart of SAR Image processing





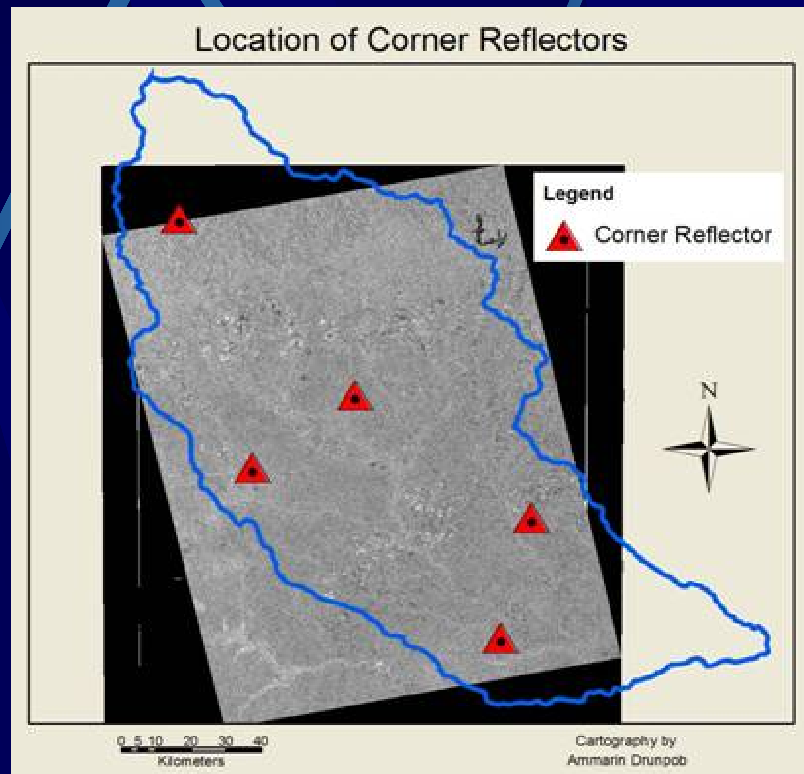
SAR Acquisitions
N
W
E
S
Single Pass preferred for modeling despite lack of southern coverage.
Double Pass has one week time delay, conditions may change.
Legend
SAR_Aug_Single
SAR_Aug_Double
watershed_dem
Elevation Meters
High : 740 m
Low : 43 m
0
10
20
40
60
80
Kilometers

# The Corner Reflector

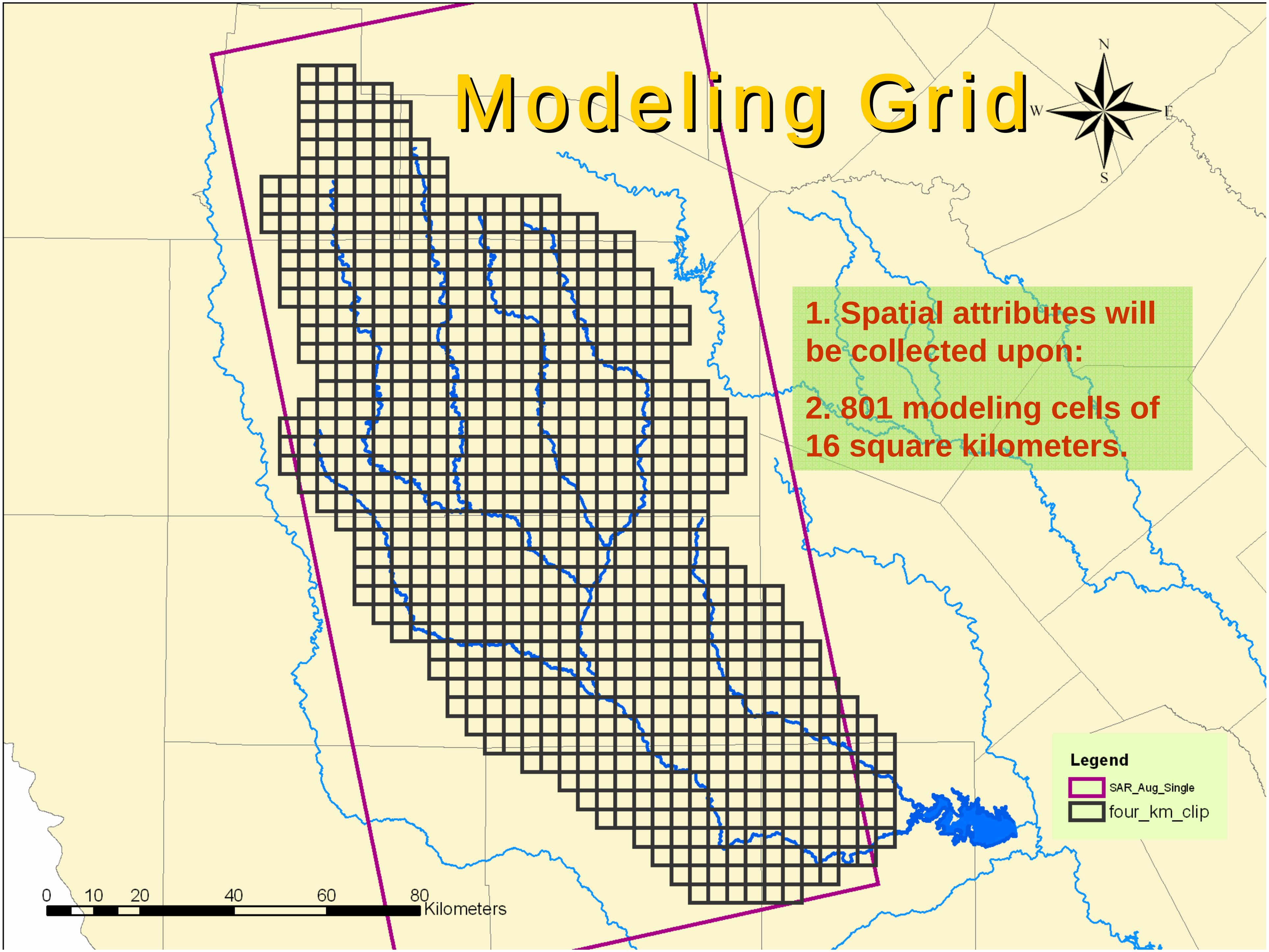
- An aluminum trihedral with the open side facing toward the SAR sensor.
- The CR is shown as a white pixel in SAR image because of the well return of the backscatter signal.

# Location of the CRs

- Five corner reflectors were installed in the CCRW prior to SAR data acquisitions in April 2004.
- Four of them falls into one scene of SAR image.
- Real-world coordinates of each CR were acquired using a sub-meter accuracy GPS unit.



# Modeling Grid




1. Spatial attributes will be collected upon:

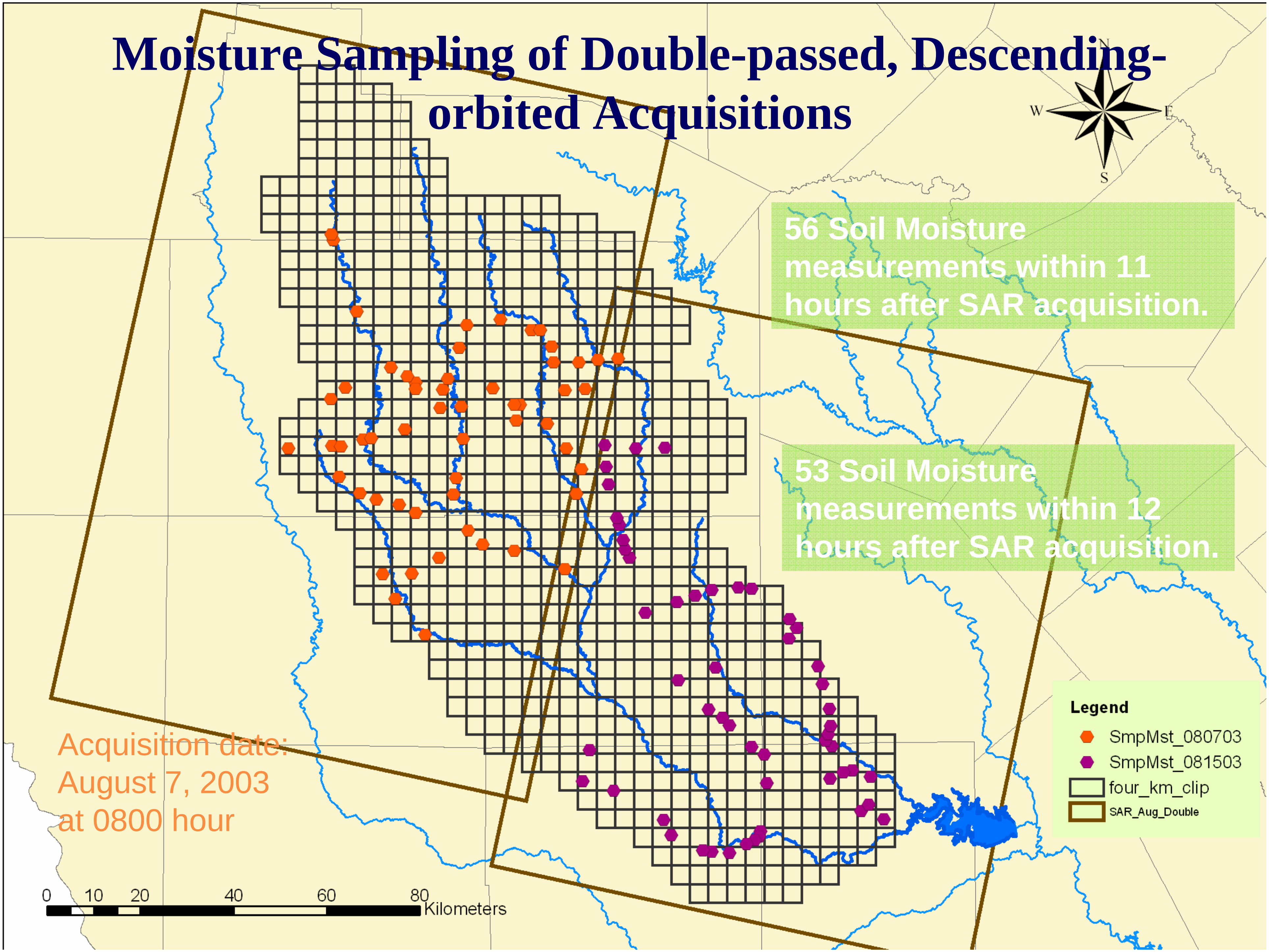
2. 801 modeling cells of 16 square kilometers.

# Ground-Truth : Sensor Technology

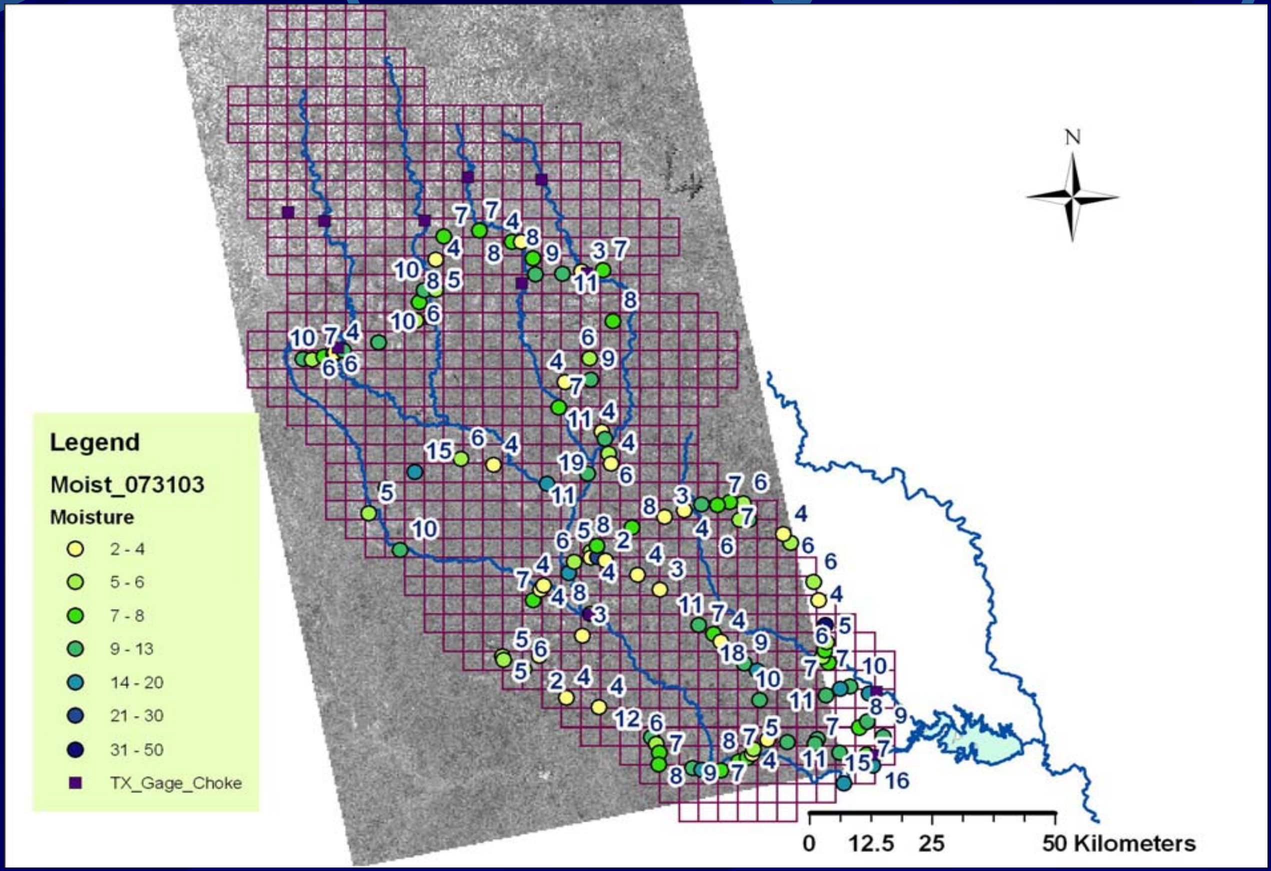
Adapted from Time domain reflectometry (TDR) web

Adapted from HOBO web

# Moisture Sampling of Double-passed, Descending-orbited Acquisitions



# SAR Imagery Basin Wide



# SAR Data Calibrations

- According to Alaska Satellite Facility (ASF)*, the ERS-1 and -2 had their absolute location accuracy of 230 m and 252 m, respectively.
- This study achieves 5 m horizontal accuracy.

*Alaska Satellite Facility, "ASF Interferometric SAR Processor (AISP) Calibration Report, version 4.0"

# Soil Moisture Prediction Techniques

- Simple Linear Regression
- Multiple Linear Regression
- Nonlinear Regression
- Neural Networks
- Genetic Programming

# Genetic Algorithm (GA)

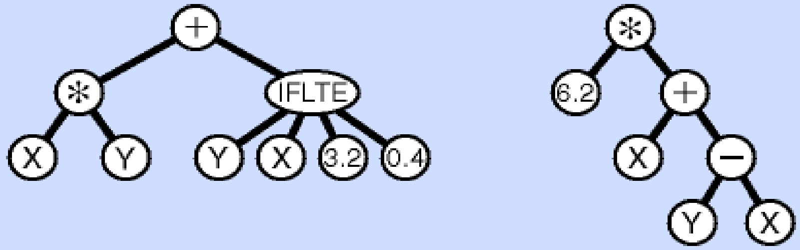
- It is a probabilistic search algorithm that iteratively transforms a set (population) of mathematical objects, each with an associated fitness value, into a new population offspring objects using
  - the **Darwinian principle of nature selection**
  - The operations that naturally occurring in genetic operations such as **crossover, mutation, and reproduction**.

Ref: Koza, J.R., Genetic Programming IV. Stanford University, CA.
E-mail: koza@stanford.edu

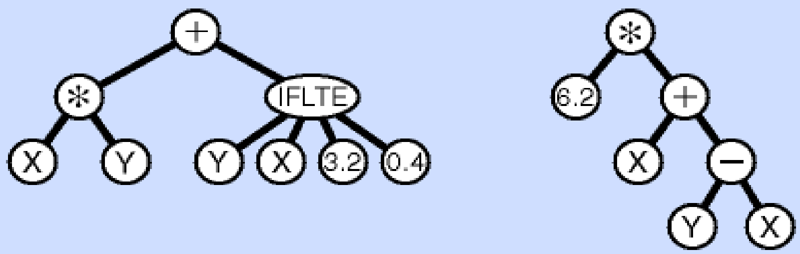
# Genetic Programming (GP)

- GP applies the approach of the Genetic Algorithm to the space of symbolic regression problems
- Genetic Operations
  - Reproduction
  - Crossover
  - Mutation

# Animation: Crossover



# Animation: Mutation



# Model Formulation

Assumption: $VMC = fn(\sigma_0, \phi, \alpha, C, A)$

- VMC = volumetric moisture content in measuring with the TDR 300 probe (%)
- $\sigma_0$ = SAR data in decibel (decibel)
- $\phi$ = percent slope (%)
- $\alpha$ = Aspect (slope direction)
- C = Land cover
- A = Soil type

# Results and Discussion

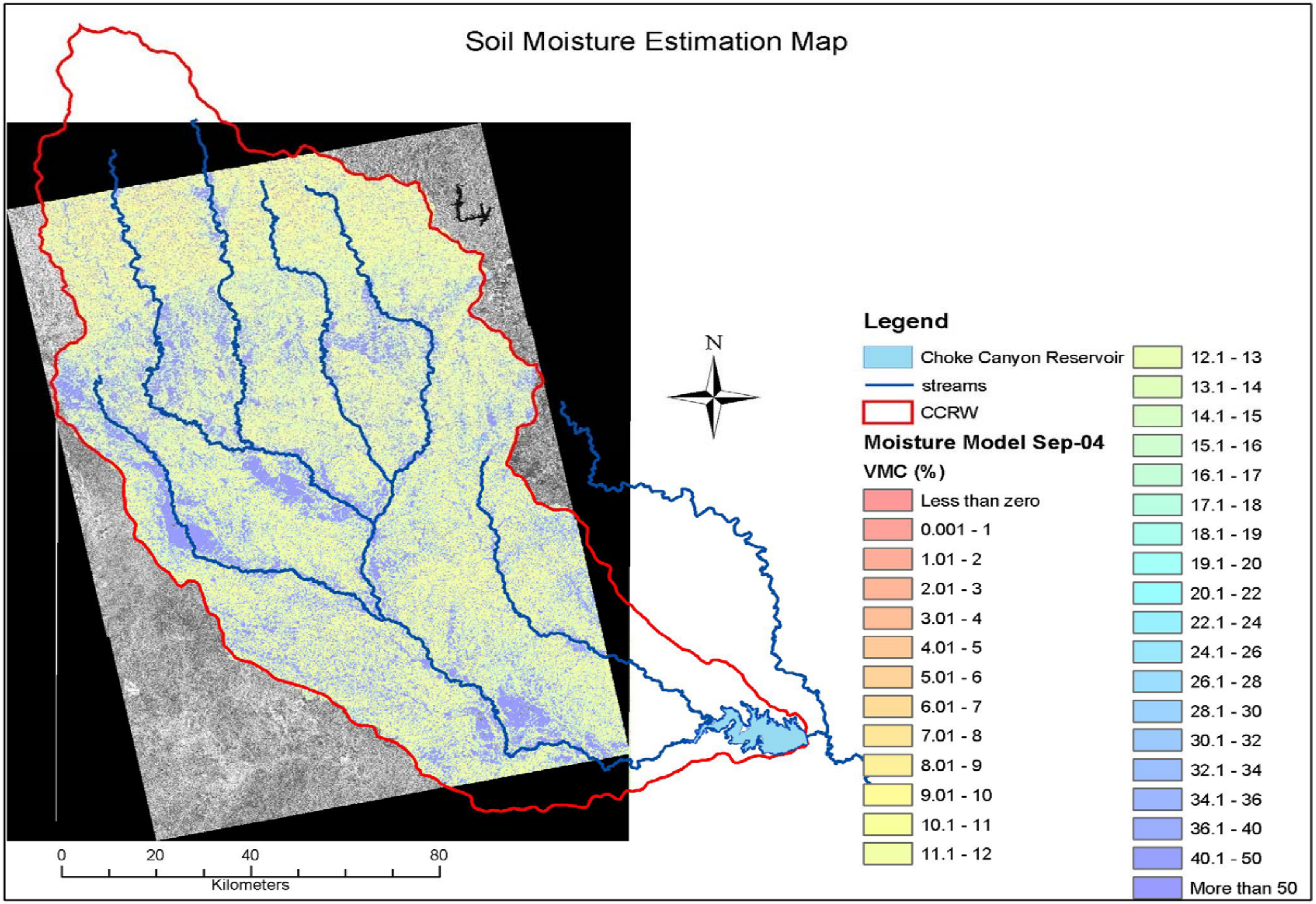
Model calibration
with the training data

| Name | Approach | Model | $R^2$ | RMSE |
|---|---|---|---|---|
| **Model 1** | **Linear Regression** | $VMC = -4.712 \cdot \sigma_0 - 13.067$ | **0.10** | **20.2** |
| **Model 2** | **Multiple Regression** | $VMC = -11.111\sigma_0 + 3.178\phi - 0.889\alpha - 198.867$ | **0.15** | **44.23** |
| **Model 3** | **GP** | | **0.83** | **10.72** |

$$VMC\ (\%) = \left\{ 3 * \left[ \frac{\sin\left(\cos\left(INC\right)\right) * Sigma}{0.9177978} + 1.531 \right] \right\} - \left(7 * SLOPE\right) - \left(3 * Sigma\right) + INC$$

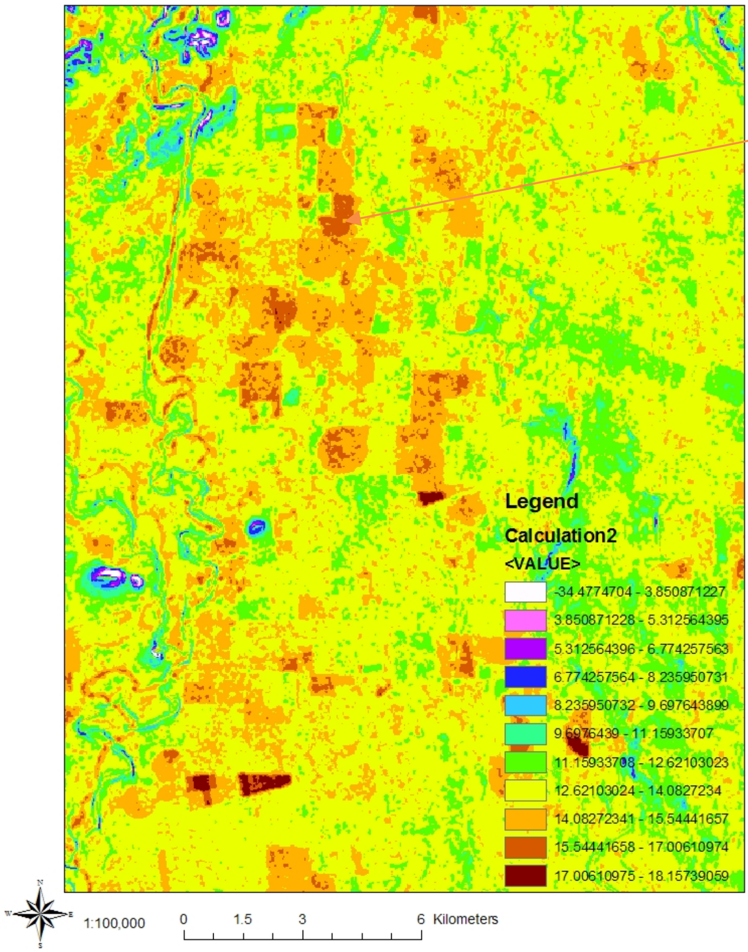
Model verification with
the unseen data

# Soil Moisture Mapping in Sep., 2004



# Agricultural Area

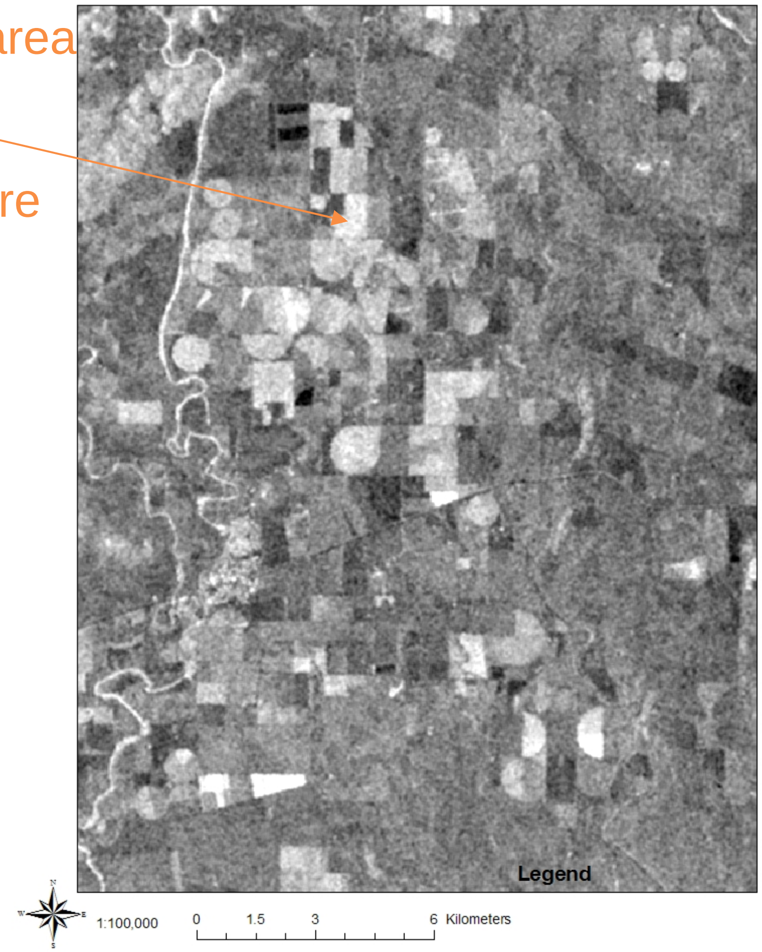
Surface Soil Moisture Prediction




Agricultural area

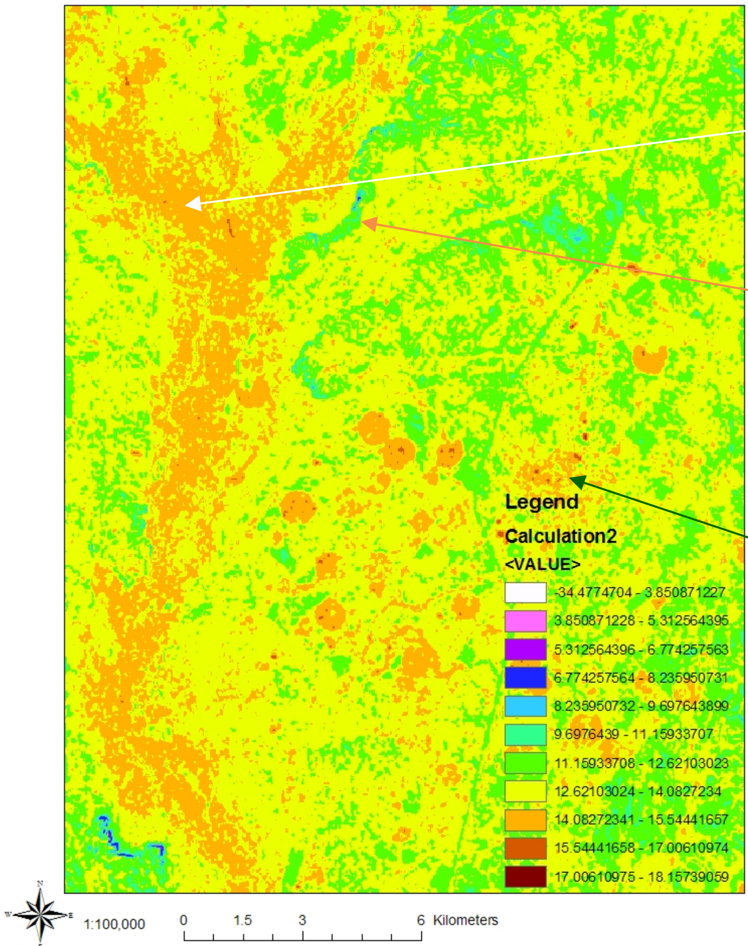
High moisture

SAR Imagery (August 1, 2003)



# Forest / Grassland

Surface Soil Moisture Prediction

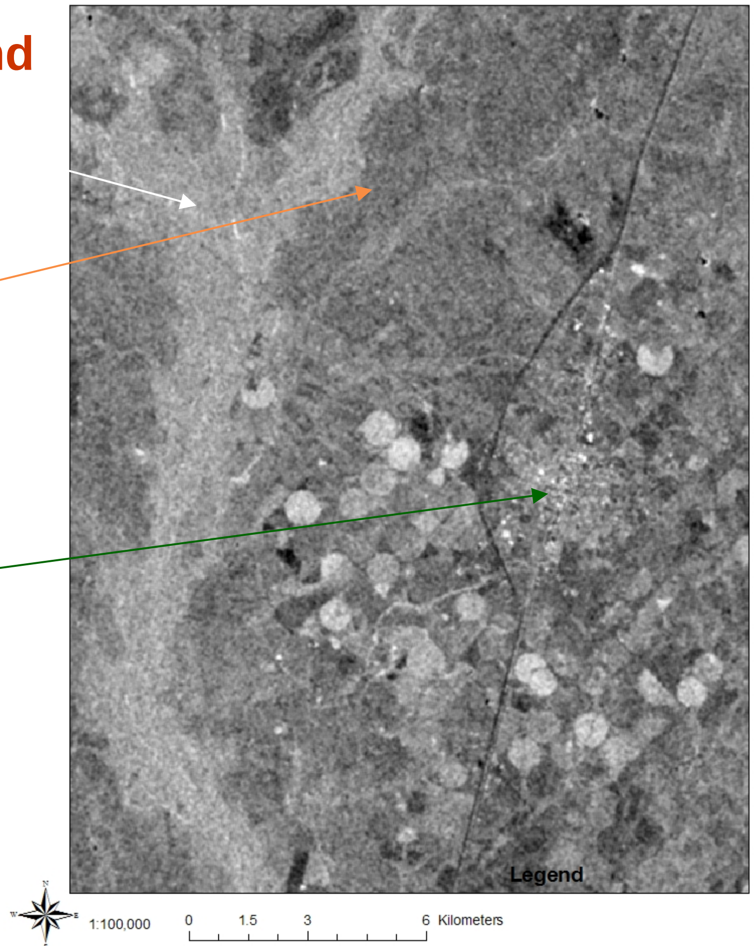



Forest/Wetland

Grassland

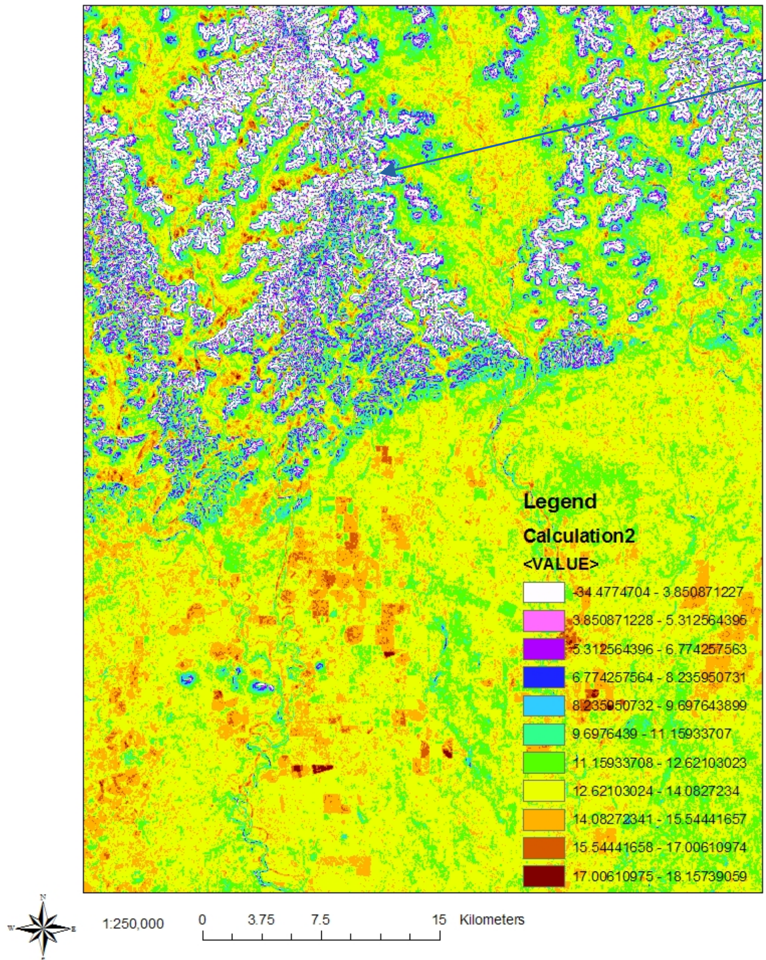
City

SAR Imagery (August 1, 2003)



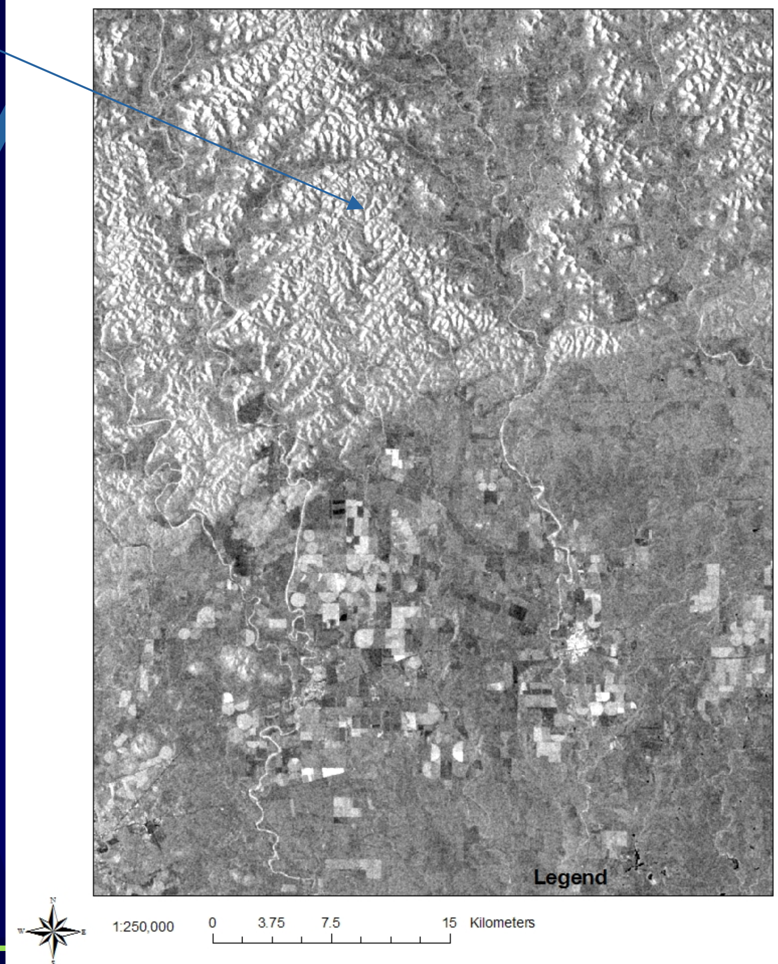
# Hill / High Slope

Surface Soil Moisture Prediction




Hills

SAR Imagery (August 1, 2003)



# Extended Work:

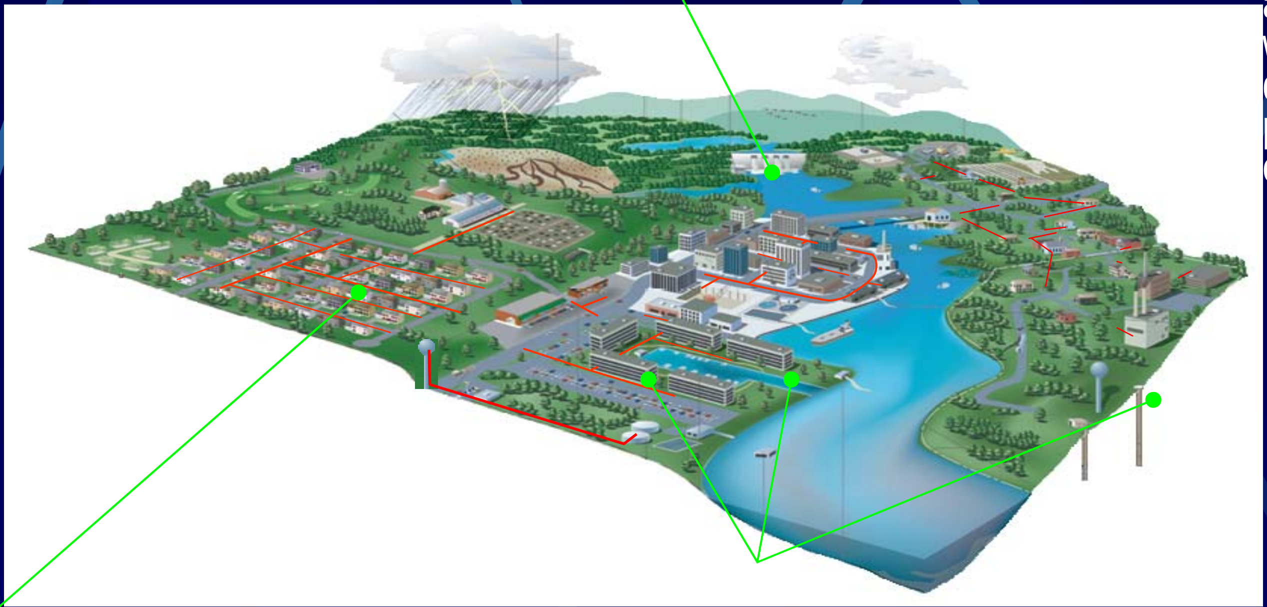
- Water cycle analysis
- Carbon cycle analysis
- Modeling coupled water and couple cycles
- Meteorological model
- Ground penetration radar
- Riparian buffer zone change detection

# Multiscale Water Infrastructure Characterization

Multi-disciplinary approach for practical solutions

Spatial and temporal GIS analysis of water supply availability, future supply-demand imbalance, and impacts on water quality and ecological systems

Remote sensing and satellite imagery for spatial assessment of drinking water source quality and quantity, and evaluation of program effectiveness and outcomes

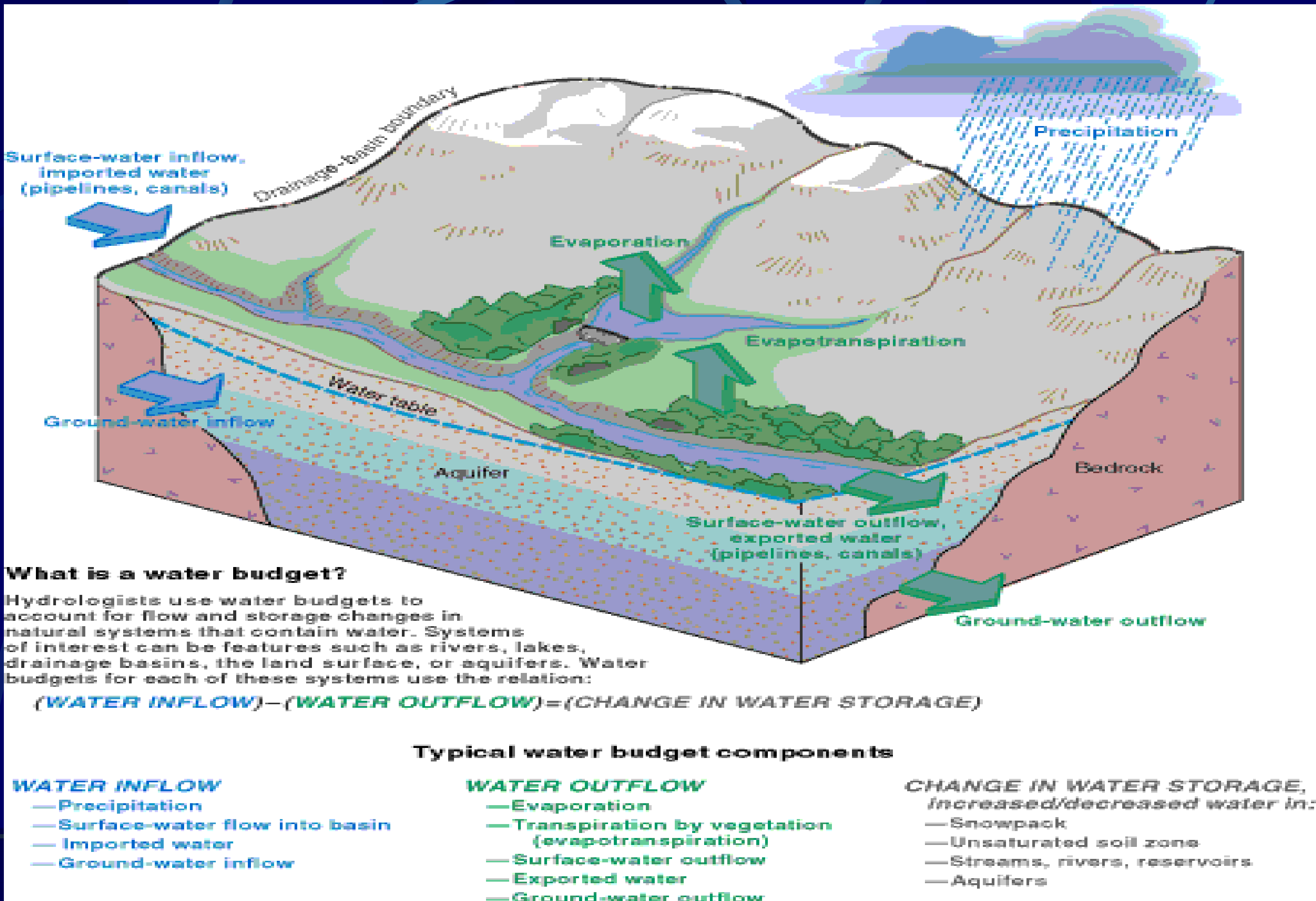


Water utility infrastructure conditions and SDWA compliance assessment under predicted future global change scenarios (climate, demographic and economic)

Regional analysis on water and wastewater infrastructure sustainability. Examples:

- CSO/SSO (eastern US, gulf states)
- Salt-water related pipe corrosion (FL, east and west coasts)
- Water reuse and allocation in ecological and human consumption (CA, TX, AZ, FL, PR, and other Plain states)

# Water Budget




ALA.
GEORGIA
87° 86° 85° 84° 83° 82° 81° 80° 79° 78° 77°
30° 29° 28° 27° 26° 25°
Century
Crestview
Milton
Niceville
Pensacola
Bonifay
Marianna
Chattahoochee
Jennings
De Funiak Spgs
Chipley
Quincy
Monticello
Madison
Jasper
Hilliard
Fernandina Beach
Fort Walton Beach
Blountstown
Bristol
Tallahassee
Live Oak
Jacksonville
Macclenny
Atlantic Beach
Jacksonville Beach
Southport
Woodville
Perry
Lake City
Orange Park
Green Cove Springs
St. Augustine
Panama City
Crawfordville
Wewahitchka
Mayo
Lake Butler
Starke
Foley
Cross City
Alachua
Port Saint Joe
Carrabelle
Trenton
Gainesville
San Mateo
Apalachicola
Steinhatchee
Palatka
Bunnell
Bronson
Ormond Beach
Williston
Pierson
Daytona Beach
Cedar Key
Ocala
Belleview
De Land
Crystal River
Tavares
Sanford
Inverness
Bushnell
Titusville
Brooksville
Orlando
Cocoa Beach
Clermont
St. Cloud
Dade City
Kissimmee
Melbourne
Tarpon Springs
Clearwater
Tampa
Lakeland
Palm Bay
Bartow
Vero Beach
Gulf of Mexico
Wauchula
Fort Pierce
Bradenton
Sebring
Port St. Lucie
Sarasota
Ona
Okeechobee
Port Salerno
Arcadia
Stuart
Venice
Indiantown
Hobe Sound
ATLANTIC OCEAN
Punta Gorda
Moore Haven
Englewood
La Belle
Palm Beach
West Palm Beach
Fort Myers
Tice
Clewiston
Boca Raton
Coral Springs
Fort Myers Beach
Pompano Beach
Fort Lauderdale
Naples
Goodland
Miami
Homestead
Key Largo
Key West
0 20 40 60 80 100 mi
0 30 60 90 120 150 km
80°15′
80°
Oakland Park
Fort Lauderdale
Pembroke Pines
Hollywood
26°
Miramar
Hallandale
Carol City
North Miami Beach
Hialeah
Miami Beach
Miami
25°45′
Coral Gables
0 4 8 mi
0 6 12 km
82° 45′
82° 30′
28°
Dunedin
Egypt Lake
Clearwater
Tampa
Largo
High Point
Pinellas Park
St. Petersburg
27°45′
Ruskin
0 4 8 mi
0 6 12 km
FLORIDA
CITIES
State capitals
County seats
Cities
BOUNDARIES
State
County
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# NEXRAD

- National Doppler Radar Network
- Provide estimation of rainfall region wide

# Thank You !

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Mr. Mark Beaman    Mr. Chris Wyatt,  Mr.  Charles Slater

Mr. Ammarin Drunpob  Mr. Javier Guerrero, Mr. Marie, Ji