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Satellite radar remote sensing: applications to the study of Earth sciences and natural resources

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Acknowledgements:

- Contributions by many colleagues/friends.
- Funding from NASA, USGS Land Remote Sensing Program, USGS Director Venture Capital Funds, USGS Volcano Hazards Program, USGS Earthquake Hazards Program, and NSF.
- World-class service and support from ASF.
- SAR imagery copyrighted by ESA, CSA, and JAXA.

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EROS (Earth Resources Observation & Science) - USGS Remote Sensing Center

AVHRR-Derived NDVI Image for June 2002

USGS

EROS – surrounded by corn fields

1-Meter KONOS image

USGS

Outline

- The very basics of radar remote sensing and InSAR
- Radar remote sensing of Earth sciences & natural resources
  - Earthquake
  - Landslide
  - Volcano
  - Aquifer
  - Surface Water and Wetland
  - Soil Moisture
  - Land Cover
  - Agriculture
- Emerging SAR/InSAR technologies
- Emerging L-Band Capabilities
- A Road Map

USGS

Radar is an instrument for measuring distance

- **In its simplest form, a radar operates by broadcasting a pulse of electromagnetic energy into space – if that pulse encounters an object then some of that energy is redirected back to the radar antenna.**
- **Precise timing of the echo delays allows determination of the distance, or "range", while measuring the Doppler frequency tells the velocity of the target.**

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Synthetic aperture radar is an active microwave sensor

- The electromagnetic wave is transmitted from the satellite. The wave propagates through the atmosphere, interacts with the Earth surface. Part of the energy is returned back and recorded by the satellite.
- By sophisticated image processing technique, both the intensity and phase of the reflected (or backscattered) signal can be calculated. So, essentially, a complex-valued SAR image represents the reflectivity of the ground surface.
- The amplitude or intensity of the SAR image is primarily controlled by **terrain slope**, **surface roughness**, and **dielectric constants**, while the phase of the SAR image is primarily controlled by **the distance** from satellite antenna to ground targets and partially controlled by the atmospheric delays as well as the interaction of microwave with ground surface.

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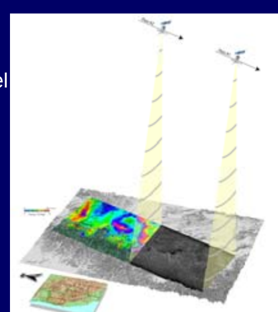
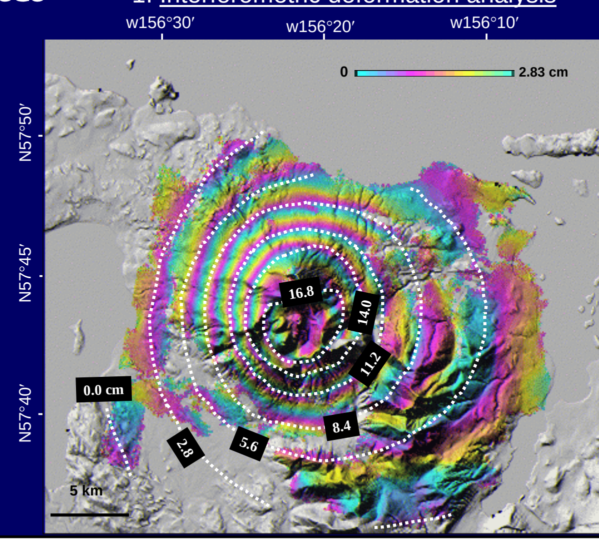
Interferometric SAR (InSAR)

- Interferometric synthetic aperture radar (InSAR) combines phase information from two or more radar images of the same area acquired from similar vantage points at different times to produce an interferogram.
- The interferogram, depicting range changes between the radar and the ground, can be further processed with a digital elevation model (DEM) to image ground deformation at a horizontal resolution of tens of meters over areas of ~100 km x 100 km with centimeter to sub-centimeter precision under favorable conditions.



USGS

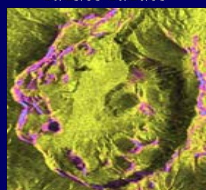
1. Interferometric deformation analysis



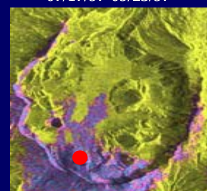
2. Interferometric coherence analysis

- A measure of changes in backscattering characteristics

10/25/95-10/26/95

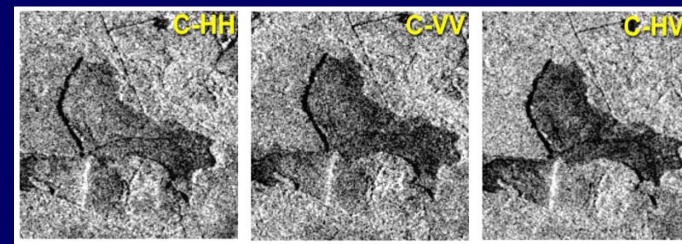


07/17/97-09/25/97



Lu et al., 2000

3. Polarimetric SAR image analysis



C-HV data will offer better potential for detection and delineation of clearcuts than C-HH and C-VV data

CANADA CENTRE FOR REMOTE SENSING
Applications Division
Canada

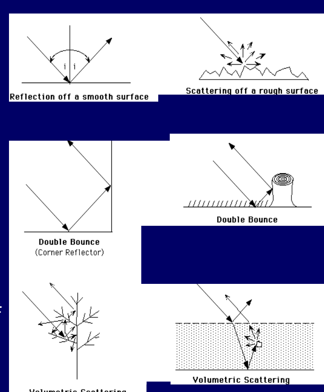
4. SAR polarimetric phase analysis

Different types of targets show different PPD behaviours

PPD:

~0° for odd refl. #

~180° for even refl. #



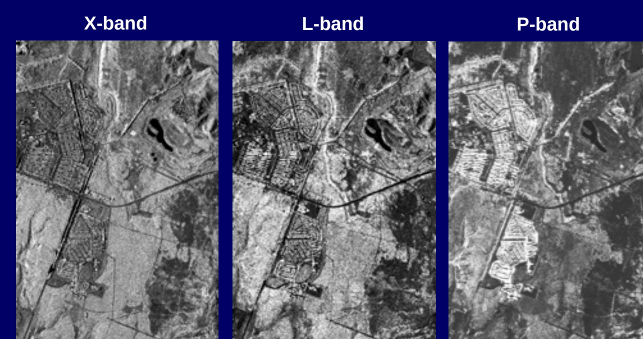
PPD ~ 0°

PPD ~ +/-180°

PPD distributed between 0° and 180°

Van Zyl, 1989

5. Analysis of SAR images at different frequencies



Synthetic Aperture Radar Satellites

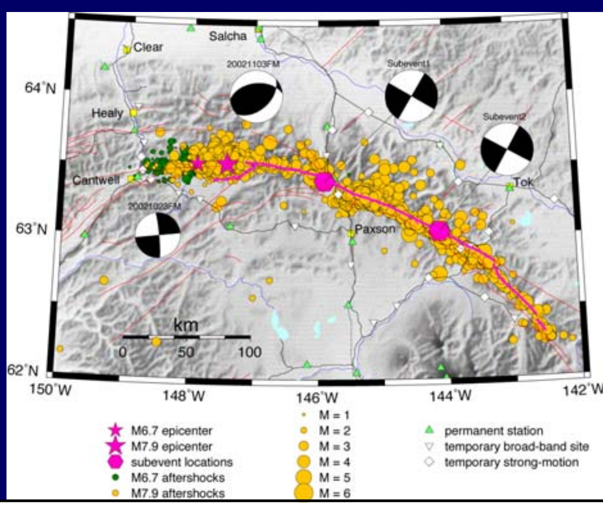
- Current and Past Sensors
  - European ERS-1, 1991-2000, C-band, 35-day repeat cycle
  - European ERS-2, 1995-now, C-band, 35-day repeat cycle (experiencing malfunctions since early 2001)
  - Japanese JERS-1, 1992-1998, L-band, 44-day repeat cycle
  - Canadian Radarsat-1, 1995-now, C-band, 24-day repeat cycle
  - European Envisat, 2002-now, C-band, 35-day repeat cycle
  - U.S. SIR-C Mission, April (10 days) and Oct (10 days), 1994 X/C/L-band, Fully Polarized
- Future Sensors
  - Japanese ALOS, 2006, L-band, 46-day repeat cycle
  - Canadian Radarsat-2, 2006(?), C-band
  - German TerraSAR-X, 2006(?), X-band
  - U.S. DOD Space-based Radar Constellations
  - U.S. ECHO+, forever?
  - …

Wavelength (λ)
- X-band: λ = ~3 cm
- C-band: λ = ~5.7 cm
- L-band: λ = ~24 cm

InSAR study of Earthquakes

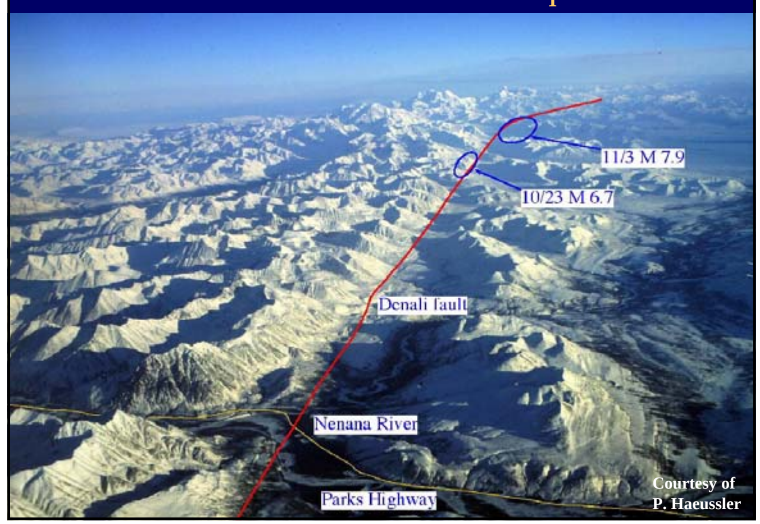
- Measuring spatial and temporal patterns of surface deformation in seismically active regions are extraordinarily useful for estimating seismic risks and improving earthquake predictions.

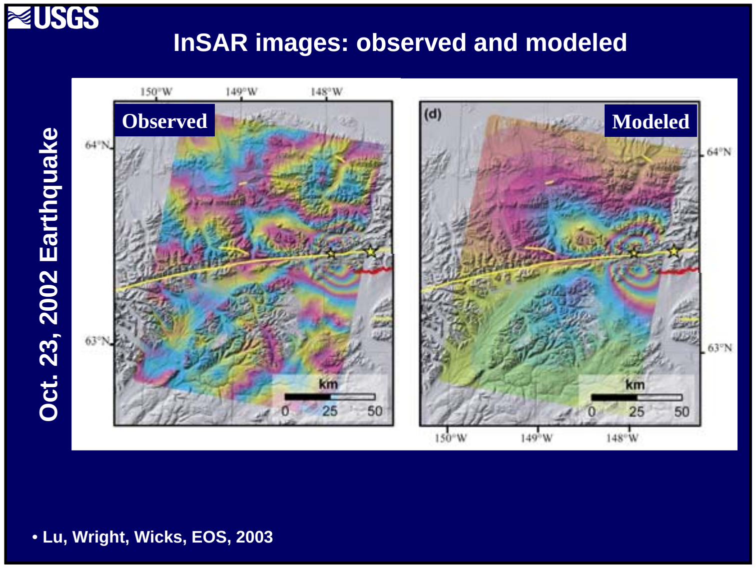
Oct. 23 and Nov 3, 2002 Denali Earthquakes

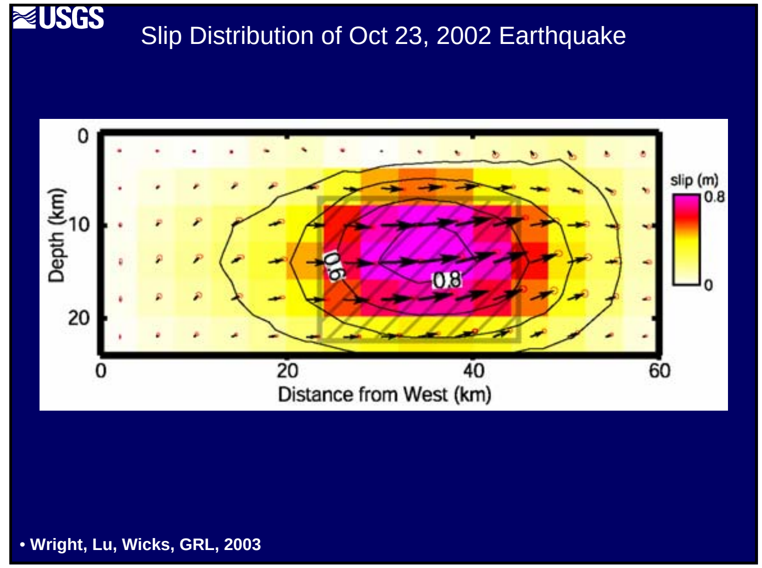


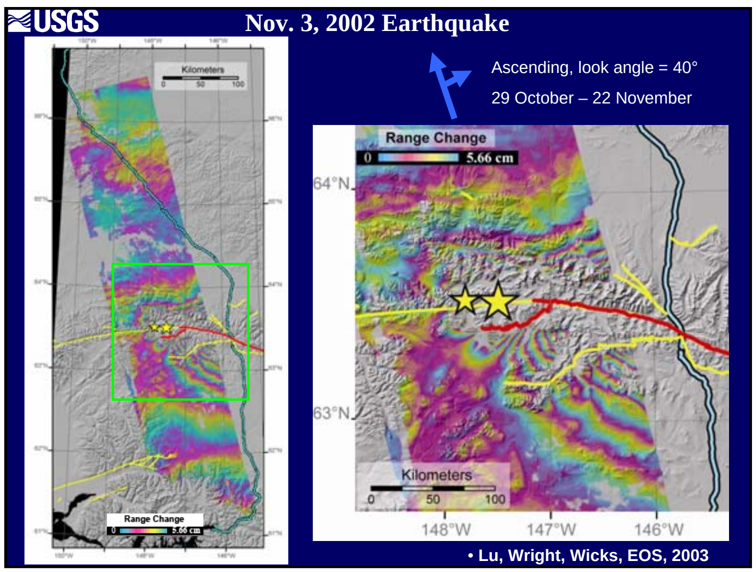
AEIC

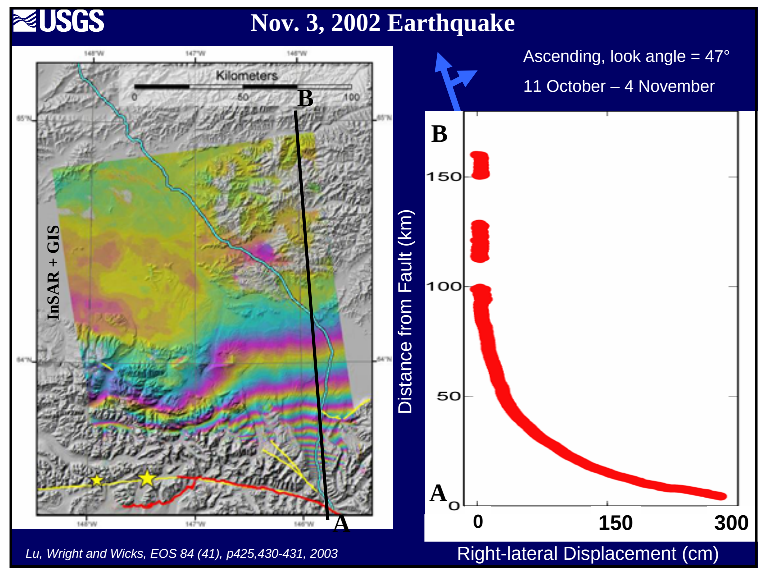
2002 Denali Fault Earthquakes




USGS
InSAR images: observed and modeled
Oct. 23, 2002 Earthquake
Observed
Modeled
(d)
km
0 25 50
150°W
149°W
148°W
64°N
63°N
• Lu, Wright, Wicks, EOS, 2003


USGS
Slip Distribution of Oct 23, 2002 Earthquake
Depth (km)
0
10
20
Distance from West (km)
0
20
40
60
slip (m)
0.8
0
0.6
0.8
• Wright, Lu, Wicks, GRL, 2003

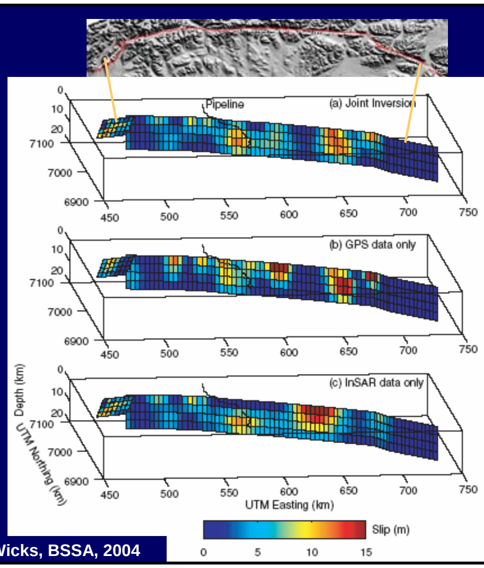

USGS
Nov. 3, 2002 Earthquake
Ascending, look angle = 40°
29 October – 22 November
Range Change
0
5.66 cm
64°N
63°N
Kilometers
0 50 100
148°W
147°W
146°W
• Lu, Wright, Wicks, EOS, 2003


USGS
Nov. 3, 2002 Earthquake
Ascending, look angle = 47°
11 October – 4 November
InSAR + GIS
Kilometers
B
A
Distance from Fault (km)
150
100
50
0
Right-lateral Displacement (cm)
0
150
300
Lu, Wright and Wicks, EOS 84 (41), p425,430-431, 2003

USGS

Nov 3, 2002 Earthquake

Slip Distribution



Joint

GPS

InSAR

• Wright, Lu, Wicks, BSSA, 2004

USGS

InSAR monitoring of landslides

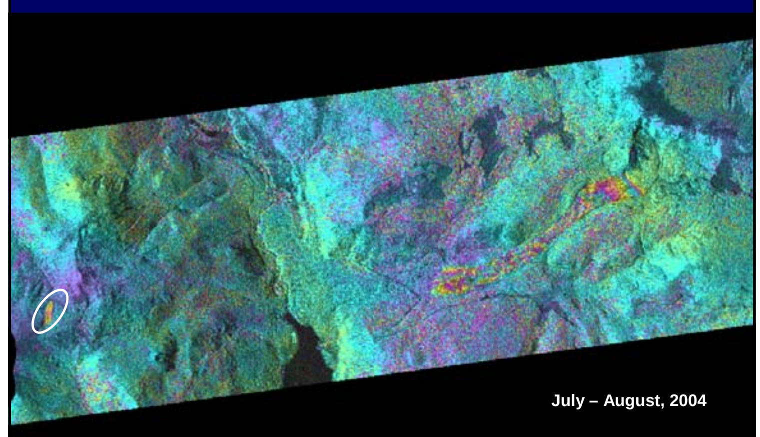
• Measuring and documenting how landslides develop and are activated are prerequisites to minimize the hazards they pose in areas of rapid urban growth.

USGS

Slumgullion Landslide, CO

USGS

InSAR image of Slumgullion landslide



0 2.83 cm

Lu and Coe, in prep, 2005

USGS

Radar remote sensing of volcanic processes

- Measuring how a volcano's surface deforms before, during, and after eruptions, provides the essential information about magma dynamics and a basis for mitigating volcanic hazards.

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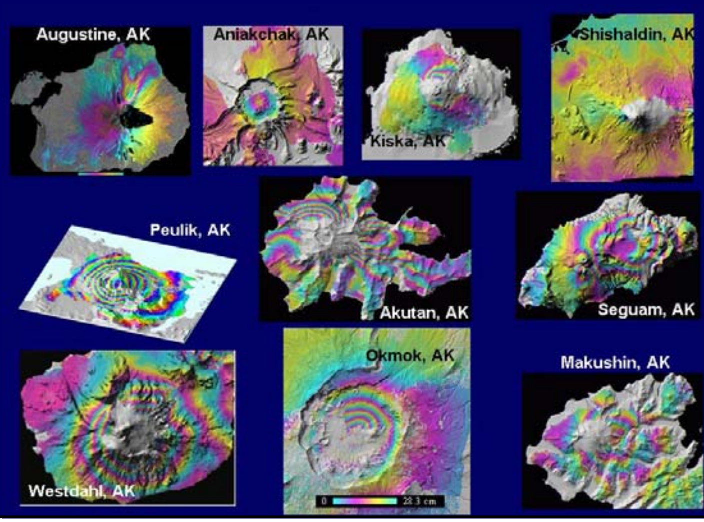
Aleutian Arc Volcanoes

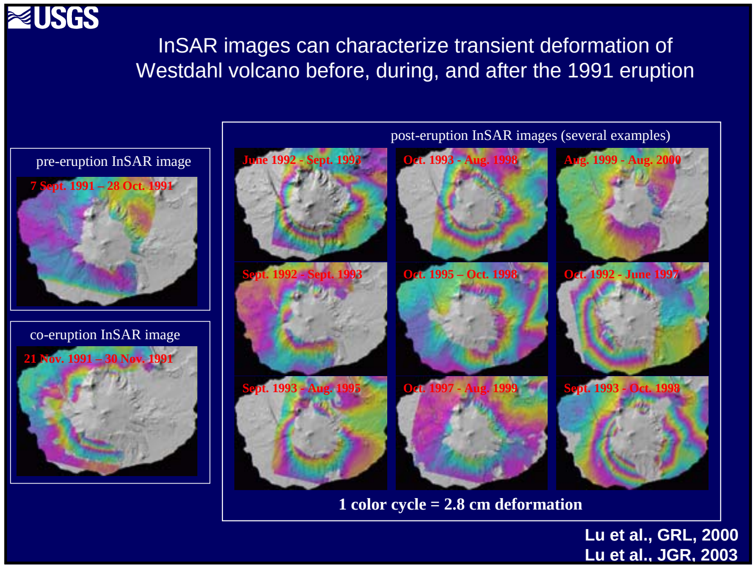
USGS

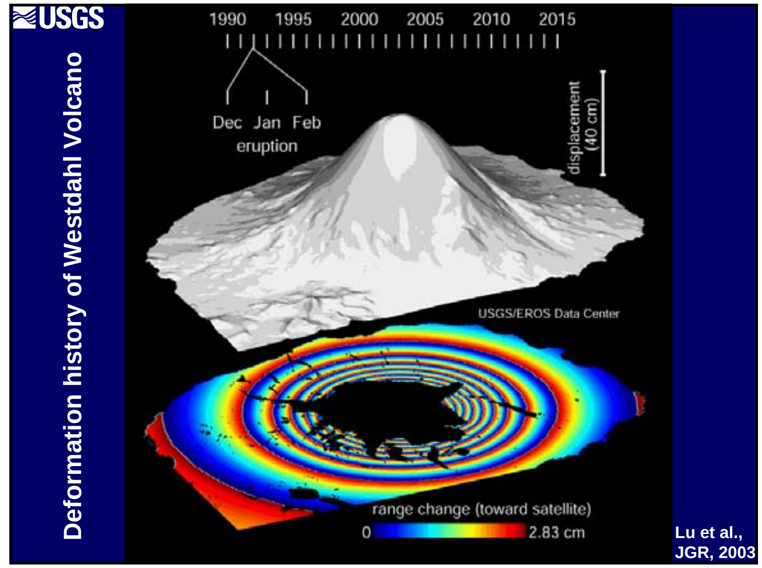
InSAR Survey of Alaskan Volcanoes

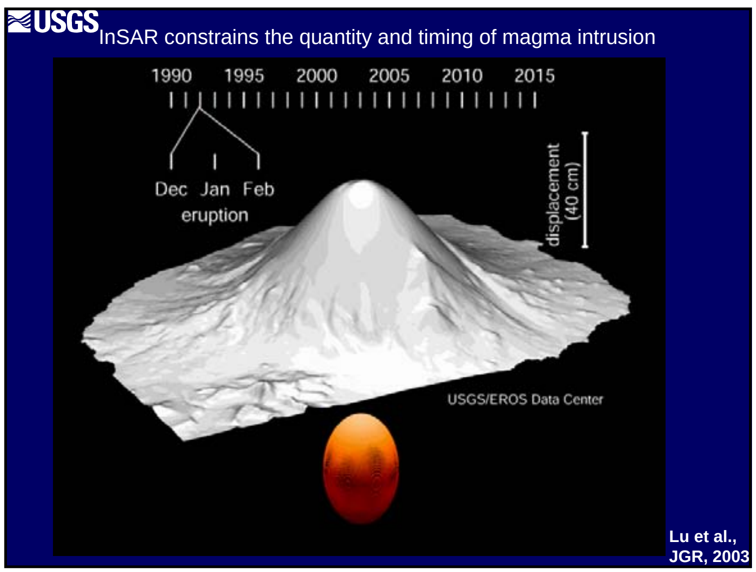


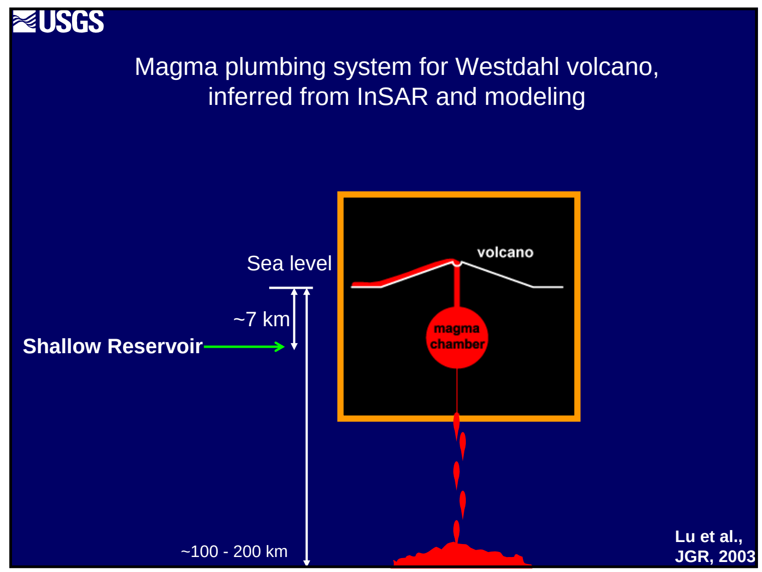
USGS

Westdahl Volcano


USGS
InSAR images can characterize transient deformation of Westdahl volcano before, during, and after the 1991 eruption
pre-eruption InSAR image
7 Sept. 1991 – 28 Oct. 1991
co-eruption InSAR image
21 Nov. 1991 – 30 Nov. 1991
post-eruption InSAR images (several examples)
June 1992 - Sept. 1993
Oct. 1993 - Aug. 1998
Aug. 1999 - Aug. 2000
Sept. 1992 - Sept. 1993
Oct. 1995 - Oct. 1998
Oct. 1992 - June 1997
Sept. 1993 - Aug. 1995
Oct. 1997 - Aug. 1999
Sept. 1993 - Oct. 1998
1 color cycle = 2.8 cm deformation
Lu et al., GRL, 2000
Lu et al., JGR, 2003


USGS
Deformation history of Westdahl Volcano
1990 1995 2000 2005 2010 2015
Dec Jan Feb
eruption
displacement (40 cm)
USGS/EROS Data Center
range change (toward satellite)
0
2.83 cm
Lu et al., JGR, 2003


USGS
InSAR constrains the quantity and timing of magma intrusion
1990 1995 2000 2005 2010 2015
Dec Jan Feb
eruption
displacement (40 cm)
USGS/EROS Data Center
Lu et al., JGR, 2003


USGS
Magma plumbing system for Westdahl volcano, inferred from InSAR and modeling
Sea level
volcano
~7 km
Shallow Reservoir
magma chamber
~100 - 200 km
Lu et al., JGR, 2003

USGS

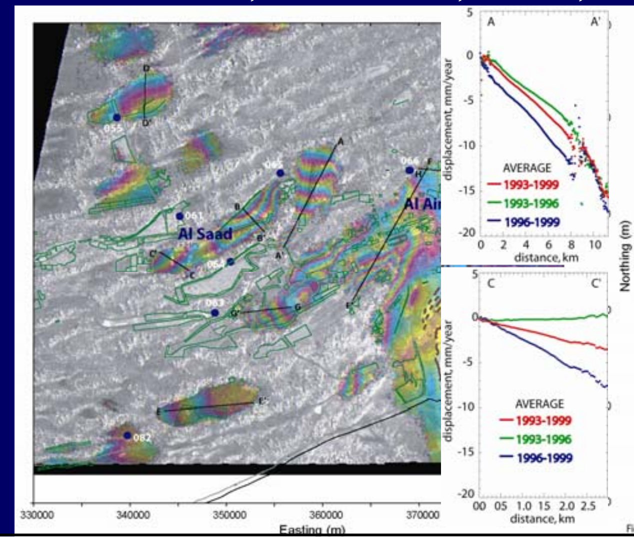
Land Subsidence Mapping – radar remote sensing of aquifer and hydrogeology

- Mapping surface subsidence and uplift related to extraction and injection of fluids in groundwater aquifers and petroleum reservoirs provides fundamental data on reservoir/aquifer properties and processes and improves our ability to assess and mitigate undesired consequences.

USGS

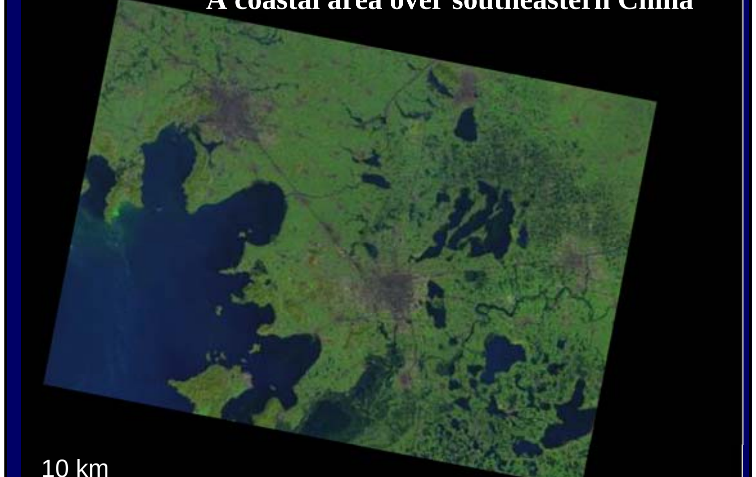
Subsidence of Al Ain, United Arab Emirates, from InSAR, 1993-1999

InSAR + GIS



USGS

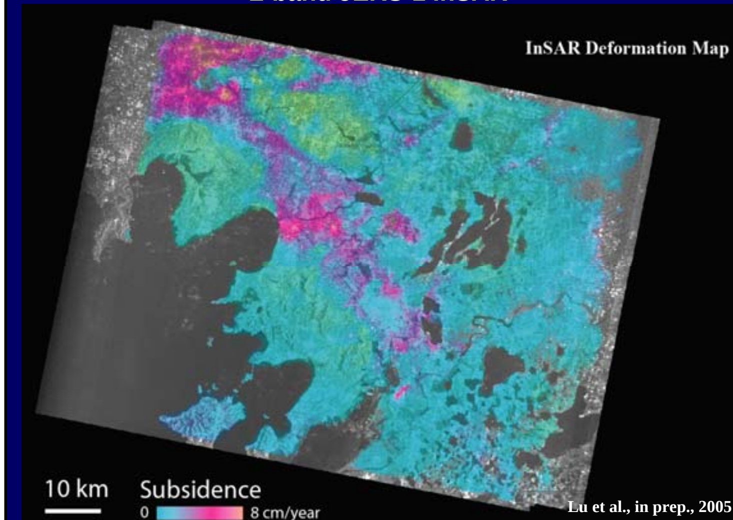
A coastal area over southeastern China



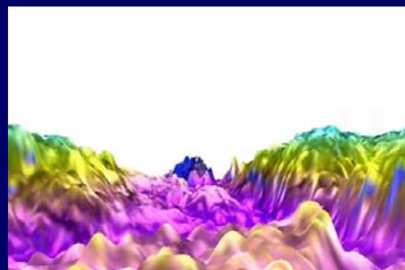
Landsat-7 image, Oct 2000

USGS

L-band JERS-1 InSAR

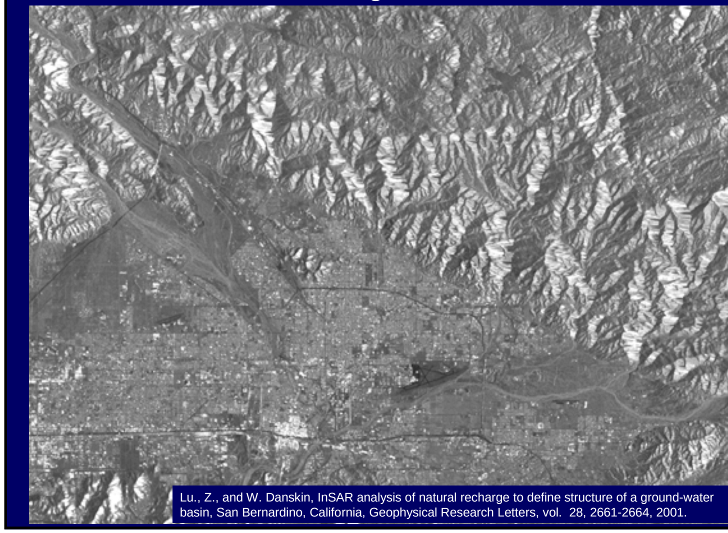


Subsidence was up to 8 cm/year



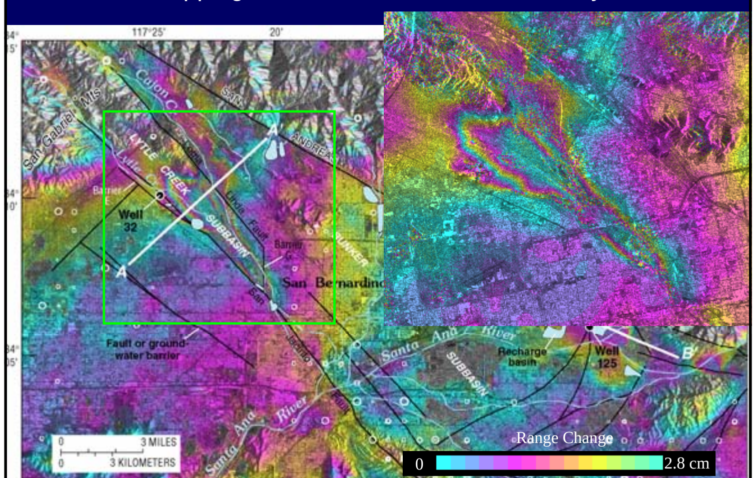
Land subsidence + GIS data layers over cities provide critical information for decision making: *Is my house sinking?*

Satellite Radar Image of San Bernardino, CA



Lu., Z., and W. Danskin, InSAR analysis of natural recharge to define structure of a ground-water basin, San Bernardino, California, Geophysical Research Letters, vol. 28, 2661-2664, 2001.

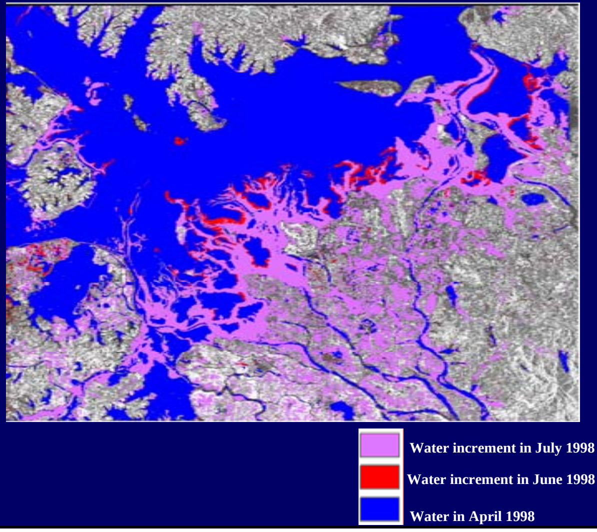
Mapping of Land Surface Deformation by InSAR



Radar remote sensing of hydrology

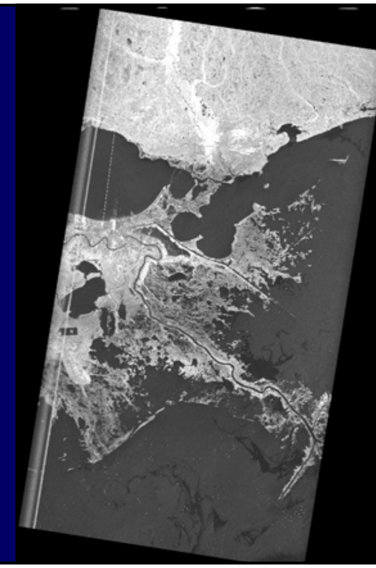
- Monitoring dynamic water-level changes beneath wetlands can improve hydrological modeling predictions and enhance the assessment of future flood events over wetlands.

Flood mapping over Po Yang Lake, using JERS-1 SAR

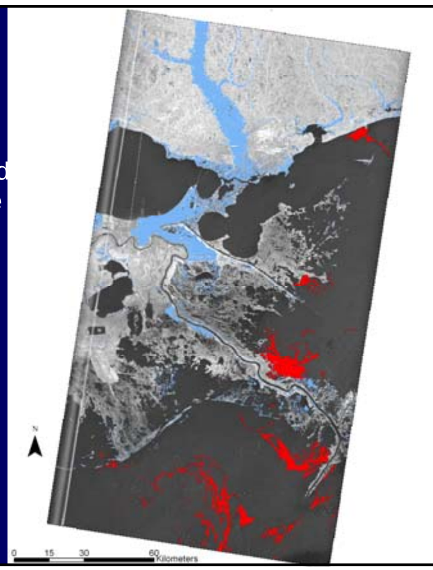


Hurricane Katrina

Radarsat-1 SAR image
Sept 2, 2005



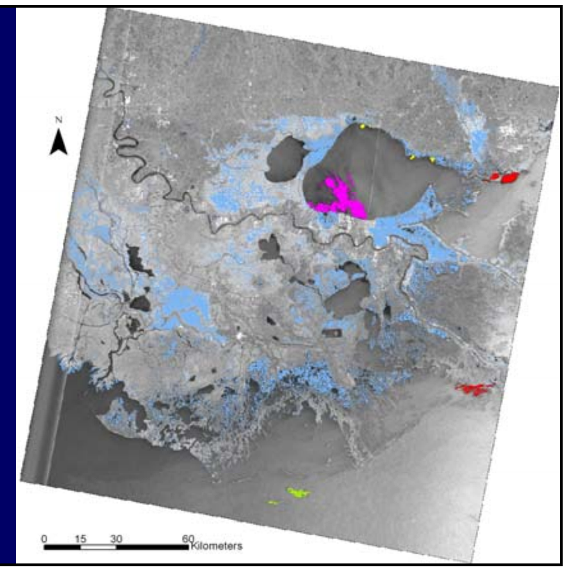
Inundation and
oil slicks mapped
from SAR image



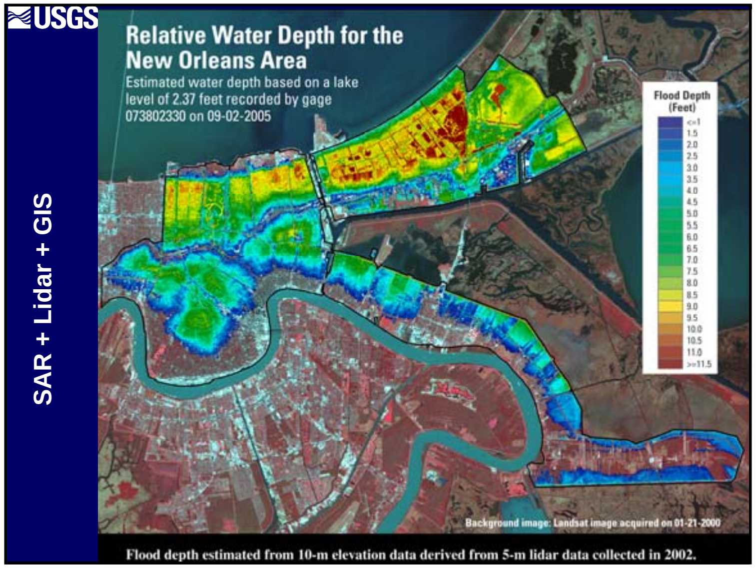
Rykhus, lu, & Jones, 2005

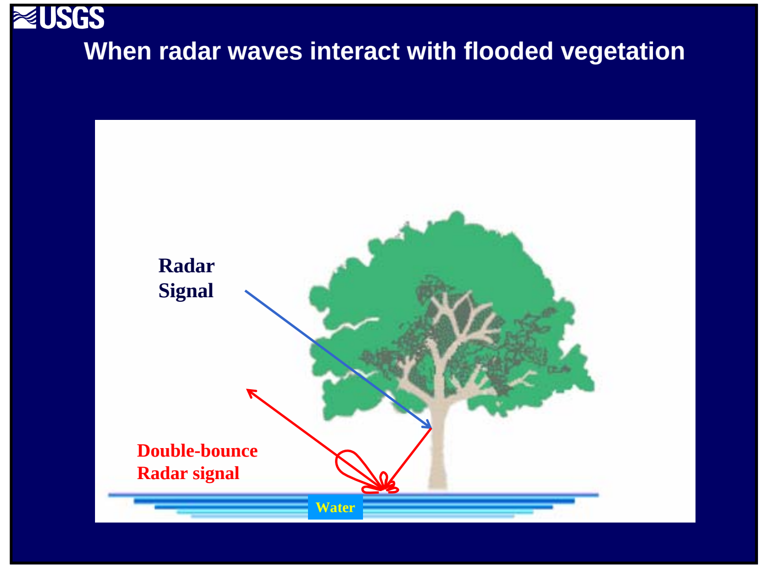
Inundation,
oil slicks,
floating debris
Mapped from
SAR image

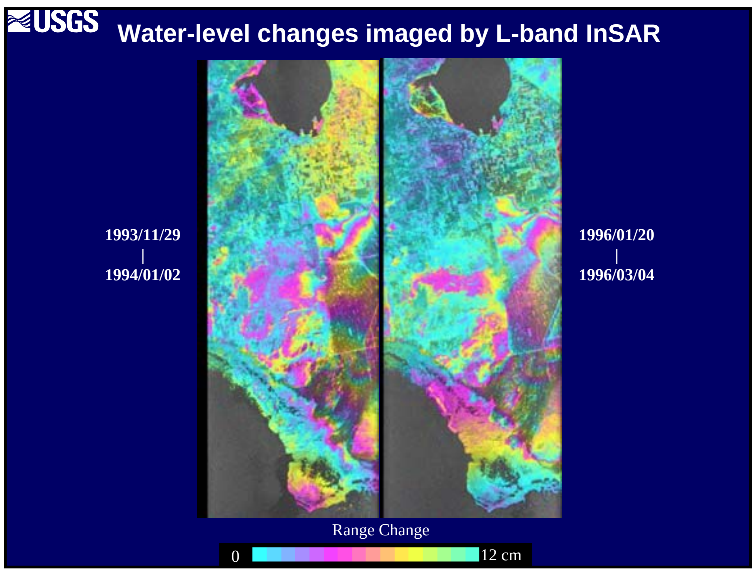
Sept 5, 2005

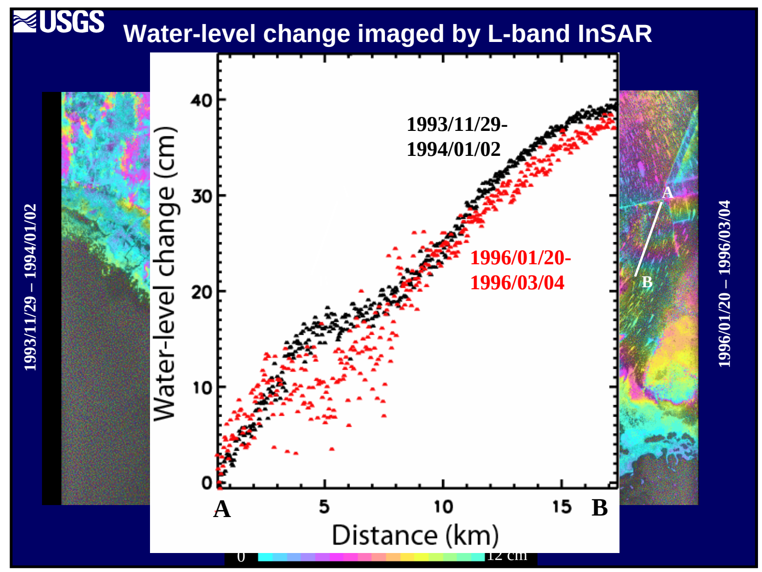


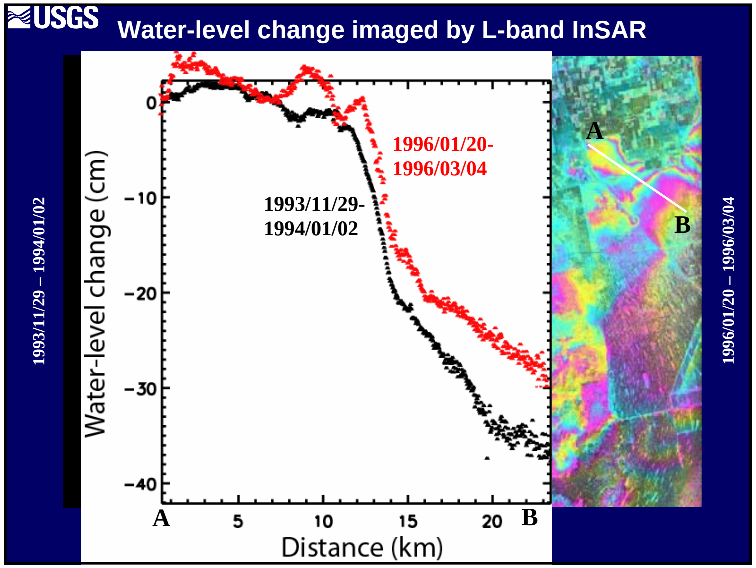
Rykhus, lu, & Jones, 2005

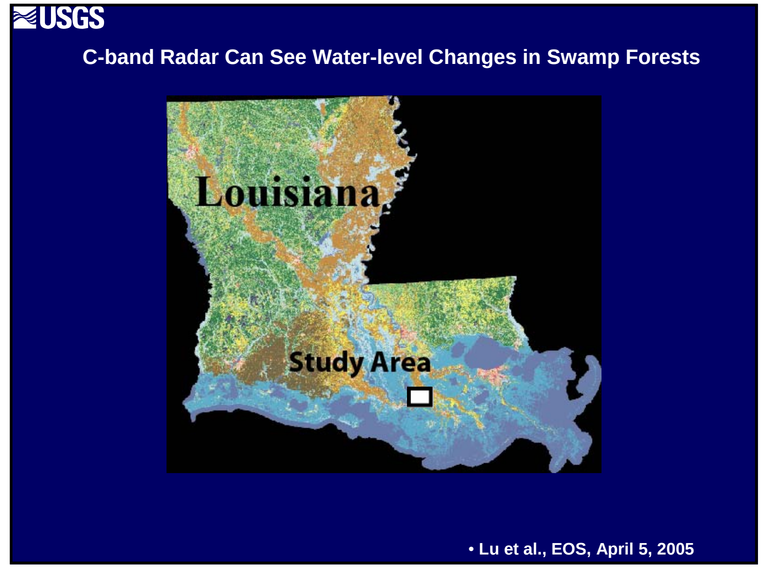

USGS
SAR + Lidar + GIS
Relative Water Depth for the New Orleans Area
Estimated water depth based on a lake level of 2.37 feet recorded by gage 073802330 on 09-02-2005
Flood Depth (Feet)
Background image: Landsat image acquired on 01-21-2000
Flood depth estimated from 10-m elevation data derived from 5-m lidar data collected in 2002.

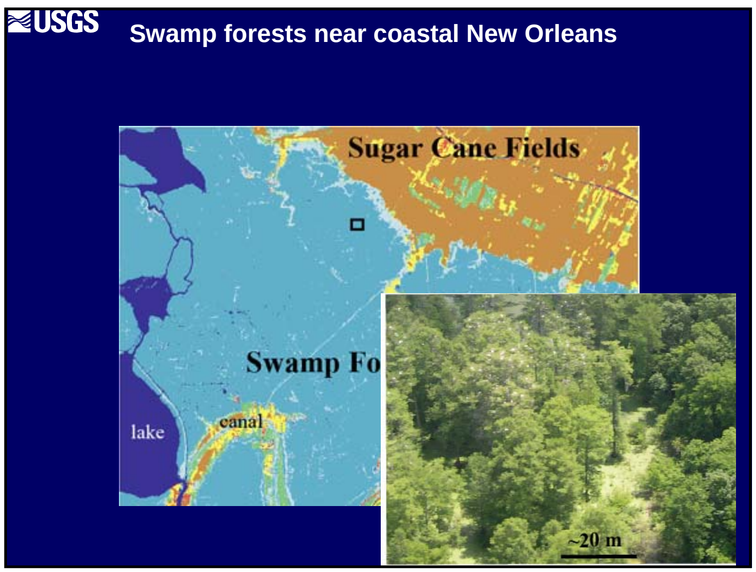

USGS
When radar waves interact with flooded vegetation
Radar Signal
Double-bounce Radar signal
Water

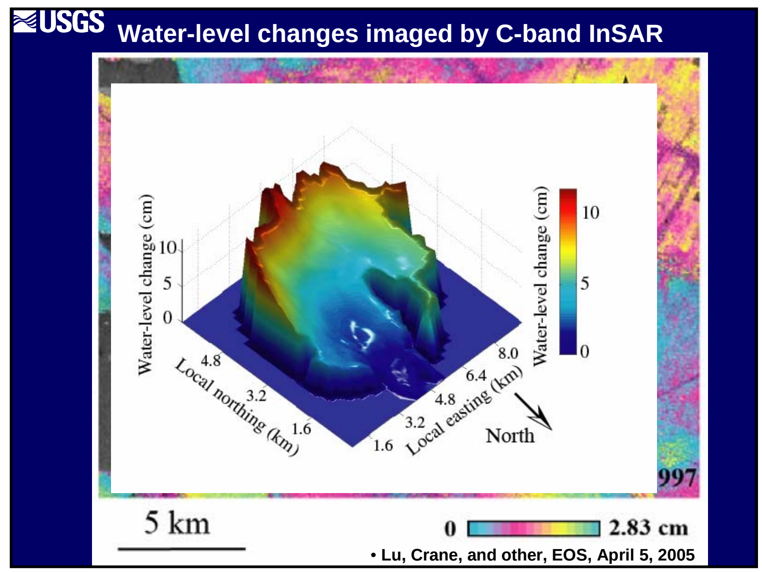

USGS
Water-level changes imaged by L-band InSAR
1993/11/29 | 1994/01/02
1996/01/20 | 1996/03/04
Range Change
0
12 cm


USGS
Water-level change imaged by L-band InSAR
1993/11/29 – 1994/01/02
1996/01/20 – 1996/03/04
Water-level change (cm)
Distance (km)
1993/11/29-
1994/01/02
1996/01/20-
1996/03/04
A
B
0
10
20
30
40
5
15
12 cm


USGS
Water-level change imaged by L-band InSAR
1993/11/29 – 1994/01/02
1996/01/20 – 1996/03/04
Water-level change (cm)
0
−10
−20
−30
−40
A
5
10
15
20
B
Distance (km)
1996/01/20-
1996/03/04
1993/11/29-
1994/01/02
A
B


USGS
C-band Radar Can See Water-level Changes in Swamp Forests
Louisiana
Study Area
• Lu et al., EOS, April 5, 2005


USGS
Swamp forests near coastal New Orleans
Sugar Cane Fields
Swamp Fo
lake
canal
~20 m


USGS
Water-level changes imaged by C-band InSAR
Water-level change (cm)
10
5
0
4.8
3.2
1.6
Local northing (km)
8.0
6.4
4.8
3.2
1.6
Local easting (km)
North
Water-level change (cm)
10
5
0
997
5 km
0
2.83 cm
• Lu, Crane, and other, EOS, April 5, 2005

Future Data and Technology Needs for Hydrology

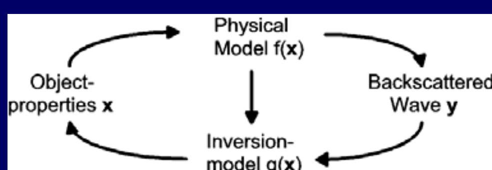
- Rapid repeat times for interferometry. Daily imagery would be ideal for flood and other hazard assessments.
- Full polarization to exploit the water-vegetation interface.
- C- and L-band imagery would provide the necessary control to map surface water elevation changes in a wide range of location.

Radar remote sensing of Soil science

- Mapping soil moisture will provide an environmental descriptor that integrates much of the land surface hydrology and is the interface for interaction between the solid Earth surface and life.

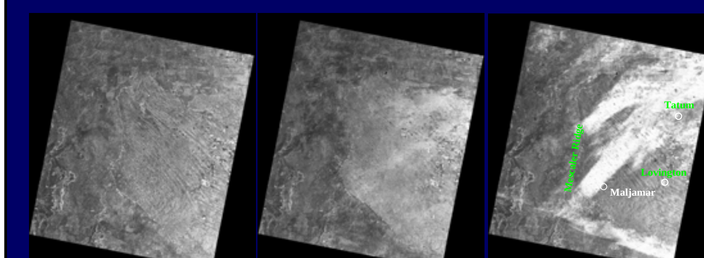
Basic Principles

- Retrieval of land surface parameters
  - Formulate a radar backscattering model
  - Apply an inversion procedure
- Ideally, we would like to start from Maxwell's equations



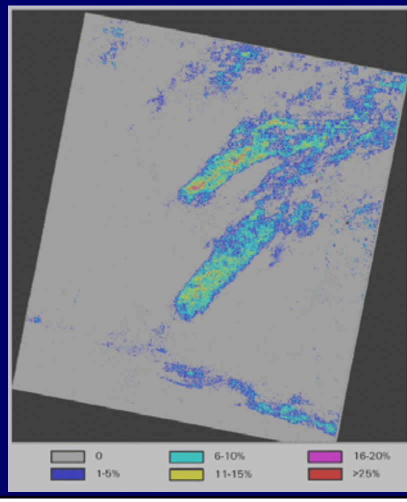
Wagner et al., 2004

Synthetic Aperture Radar (SAR) images over Carlsbad, New Mexico



19921005 19930920 19951227

Mapping of change in soil moisture, Carlsbad, New Mexico



Lu and Meyer, IJRS, 2002

Backscattering properties of soil

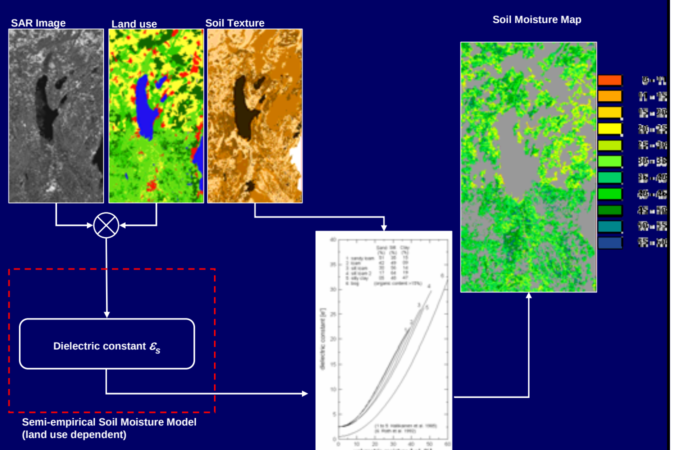
A Radar backscsattering model (i.e., **Integral Equation Model)**

$$\sigma_{qp}^{s}(s) = \frac{k^2}{2}\exp(-2k_z^2 s^2)\sum_{n=1}^{\infty} s^{2n}\left|I_{qp}^{n}\right|^2 \frac{W^n(-2k_x,0)}{n!}$$

The surface backscattering components σ_{hh}, σ_{vv} and σ_{hv} can be simulated for a wide range of incidence angle, surface dielectric and roughness properties, corresponding to a rang of soil moisture values.

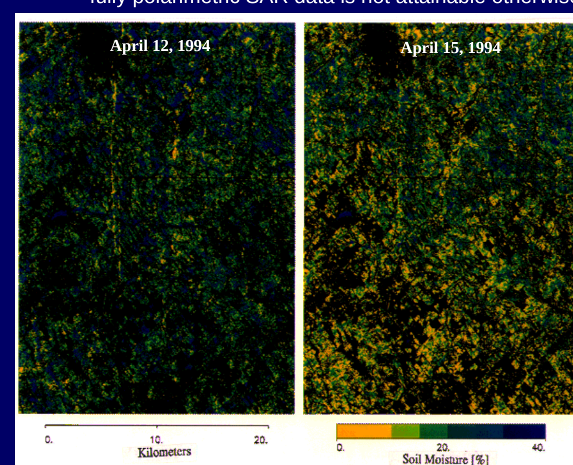
By comparing simulated backscattering values with those observed, soil moisture can be inferred (Intense computation => ARSC)

The Semi-Empirical SAR Soil Moisture Retrieval Scheme



Mauser et al., 2004

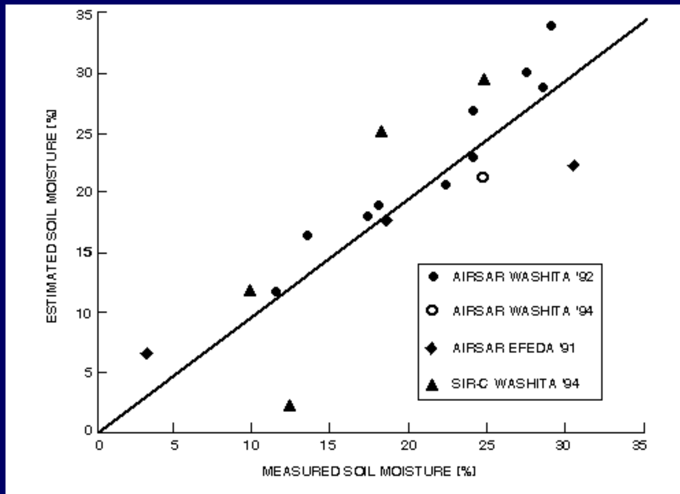
Mapping soil moisture with SIR-C SAR images. The horizontal resolution (several meters) of soil moisture imagery derived from fully polarimetric SAR data is not attainable otherwise



Dubois et al., 1995

USGS

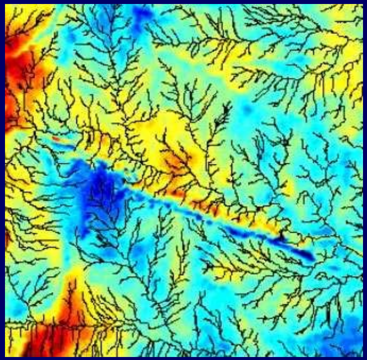
Mapping soil moisture with AIRSAR images



Dubois et al., 1995

USGS

Inferring soil moisture with InSAR images



Drying (blue) and moistening (yellow/red) between two SAR acquisitions in an arid region of Colorado inferred from InSAR. Range change was interpreted as being due to changes in penetration depth that results from change in soil moisture.

Nolan & Fatland, 2003

USGS

Future Data and Technology Needs for Soil Moisture Science

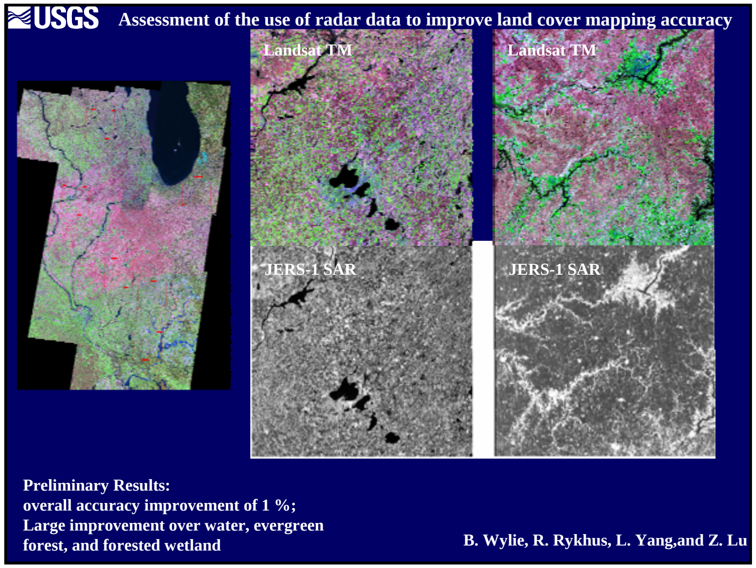
- Rapid repeat times for interferometry. Daily imagery would be ideal to map dynamic changes in the surface water content. A minimum requirement would be weekly coverage.

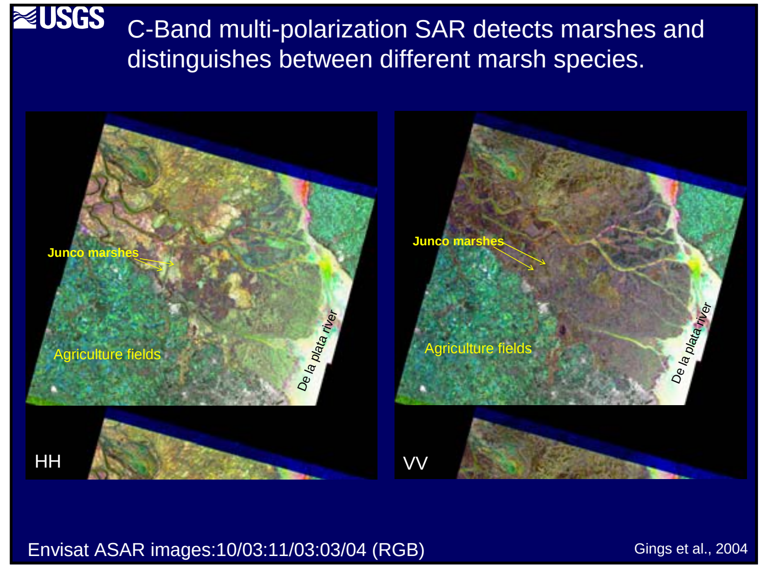
- Multi-wavelength capabilities for imaging soil moisture content at varied penetration depths. Ideally, a multi-wavelength mission(s) could image soil moisture at depths of about a few cm and tens of cm. The depth penetration would produce true 4-dimensionsa soil moisture maps that would provide the basis for hydrology and ecology studies.

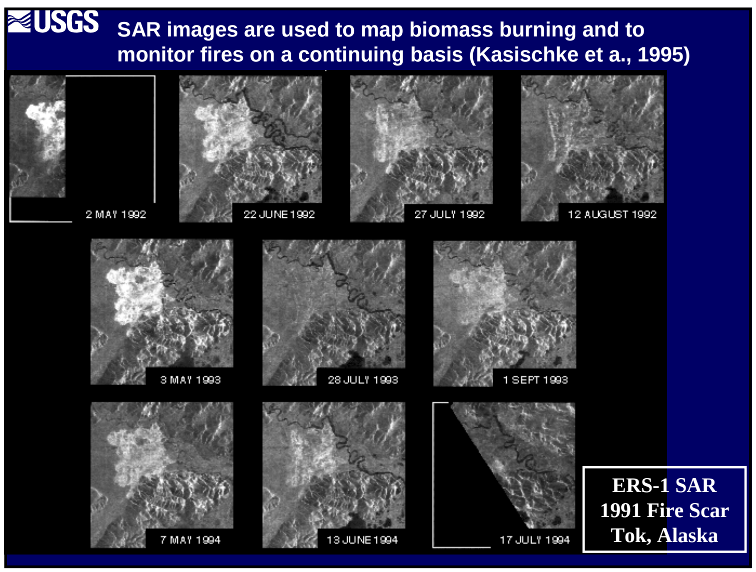
- Full polarization.

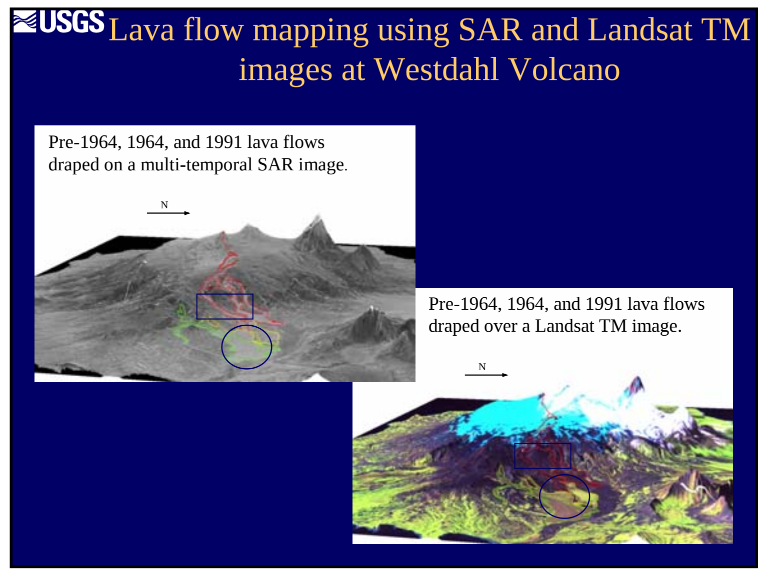
USGS

Radar remote sensing of land-cover characterization


USGS
Assessment of the use of radar data to improve land cover mapping accuracy
Landsat TM
Landsat TM
JERS-1 SAR
JERS-1 SAR
Preliminary Results:
overall accuracy improvement of 1 %;
Large improvement over water, evergreen
forest, and forested wetland
B. Wylie, R. Rykhus, L. Yang,and Z. Lu


USGS
C-Band multi-polarization SAR detects marshes and distinguishes between different marsh species.
Junco marshes
Agriculture fields
De la plata river
HH
Junco marshes
Agriculture fields
De la plata river
VV
Envisat ASAR images:10/03:11/03:03/04 (RGB)
Gings et al., 2004


USGS
SAR images are used to map biomass burning and to monitor fires on a continuing basis (Kasischke et a., 1995)
2 MAY 1992
22 JUNE 1992
27 JULY 1992
12 AUGUST 1992
3 MAY 1993
28 JULY 1993
1 SEPT 1993
7 MAY 1994
13 JUNE 1994
17 JULY 1994
ERS-1 SAR
1991 Fire Scar
Tok, Alaska


USGS
Lava flow mapping using SAR and Landsat TM images at Westdahl Volcano
Pre-1964, 1964, and 1991 lava flows draped on a multi-temporal SAR image.
N
Pre-1964, 1964, and 1991 lava flows draped over a Landsat TM image.
N

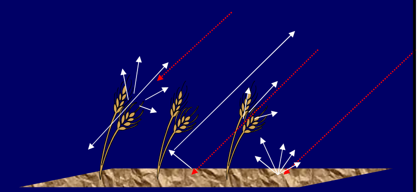
USGS

Radar remote sensing of Agriculture

USGS

SAR Backscattering from Agricultural Fields

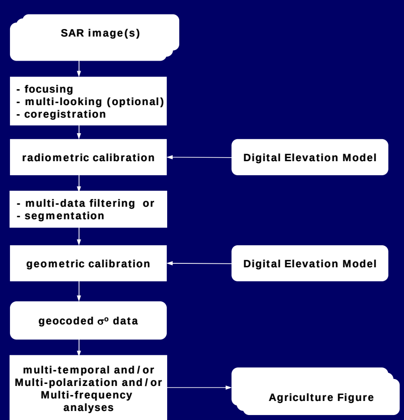
- Soil surface roughness
- Soil surface moisture
- Soil type
- Crop species
- Vegetation biomass
- Vegetation moisture
- Land slope
- Seed row direction
- others



Challenges: All of agriculture parameters are a function of
- Acquisition mode (geometry, frequency, polarisation)
- Acquisition time and interval
- Temporal signature

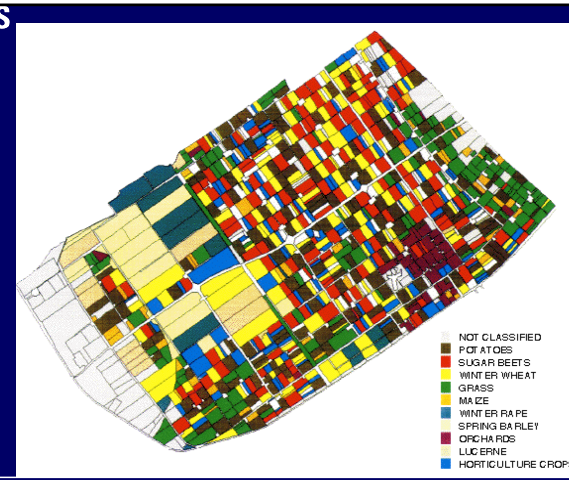
USGS

Analysis Approach



Parallel Computation

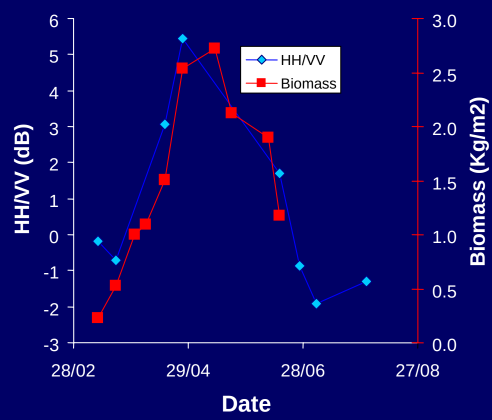
USGS



Crop classification derived from multi-temporal C-band ERS-1 SAR images over Flevoland, the Netherland (Schotten et al, 1995). For regions with persistent clouds, SAR imagery allows frequent monitoring of crop growth.

USGS

HH/VV and biomass temporal variation over wheat fields

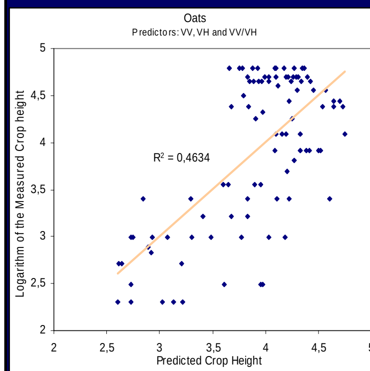


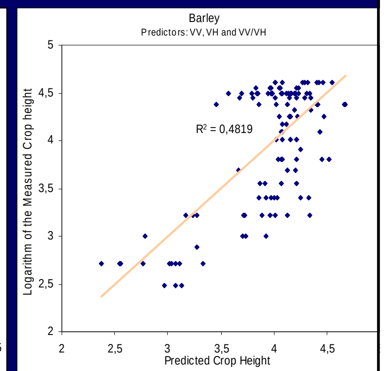
(Mattia et al., 2003)

USGS

Crop Height Estimation

Log(Measured crop height) = $a_0 + a_1 * VV + a_2 * VH + a_3 * VV/VH$

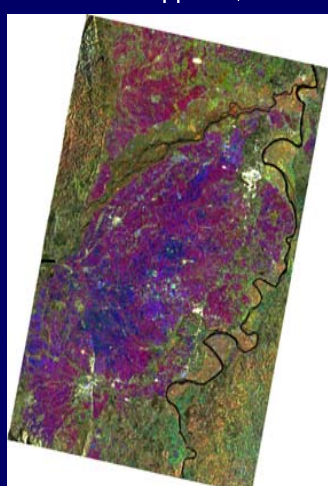




Holecz et al., 2004

USGS

Rice - Philippines, Multi-temporal ENVISAT ASAR AP data

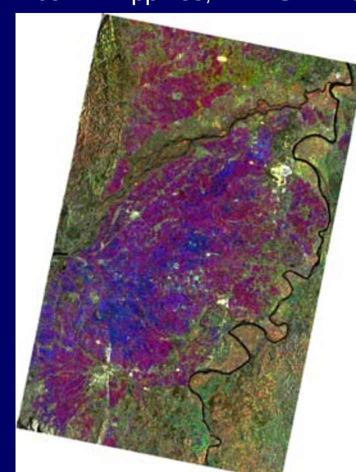


13 November 2003
02 December 2003
18 December 2003
06 January 2004
22 January 2004
10 February 2004
16 March 2004
20 April 2004

Holecz et al., 2004

USGS

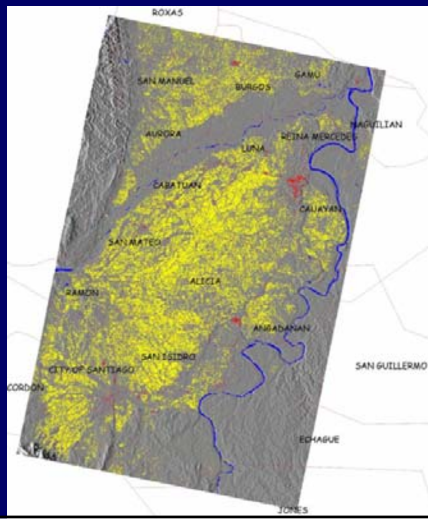
Rice - Philippines, ENVISAT ASAR AP & Radarsat-1 data



13 November 2003 ASAR
18 December 2003 ASAR
06 January 2004 Radarsat-1

Holecz et al., 2004

Rice Acreage based on ASAR AP & Radarsat-1



Holecz et al., 2004

South Africa - Maize, Multi-temporal Radarsat-1 data

Radarsat-1 FB

04 Nov 2003
21 Nov 2003
28 Nov 2003

Holecz et al., 2004

Future Data and Technology Needs for Land Cover/Vegetation/Agriculture Sciences

- Zero baseline L-HH InSAR for estimating temporal decorrelation, which empirical models relate to vegetation characteristics.
- Short repeat period that minimizes temporal decorrelation, useful for both vegetation and deformation.
- Fully polarimetric capability.
- Polarimetric InSAR for improved vertical structure accuracy and land-cover type discrimination.
- Multiple frequency for providing two height estimates used to expand observation.

Future Trends in Radar Remote Sensing

- From single image to multi-temporal images
- From single polarization to dual/full polarization
- 4-D spatial-temporal analysis
- Intense computation and parallel processing

USGS Emerging SAR/InSAR technologies

Permanent Scatterer InSAR – Improve deformation measurement accuracy of conventional InSAR

Cross-Platform InSAR – Generate high-resolution DEM by manipulating radar signals from different platform/sensors

Operational InSAR Processing System – Improve InSAR processing throughput and lay the foundation for routine monitoring seismic/volcanic/landslide deformation

ScanSAR InSAR – Improve spatial coverage of conventional InSAR to image large-scale deformation

Polarimetric InSAR – Mapping vegetation height through InSAR analysis of polarimetric SAR signal

Multi-temporal, polarimetric SAR – Improve land cover mapping and characterization over regions where weather conditions plague optical remote sensing

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USGS Persistent Scatterer InSAR (PSInSAR)

Differential Phase Equation

For pixel *n* in interferogram *i:*

$$\phi_{n,i} = \phi_{\varepsilon,n,i} + \phi_{defo,n,i} + \phi_{APS,n,i} + \phi_{orbit,n,i} + \sigma_{n,i}$$

DEM Error Term

Deformation in LOS

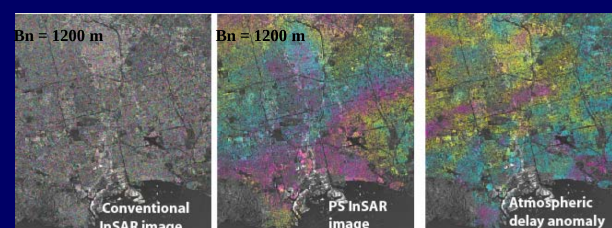
Atmospheric Phase Term

Orbit Error Term

Noise

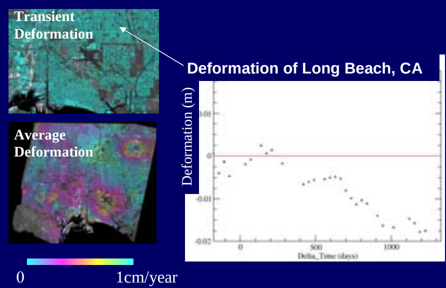
USGS Improve InSAR technique

- Permanent Scatterer InSAR



Improve InSAR technique

- Permanent Scatterer InSAR



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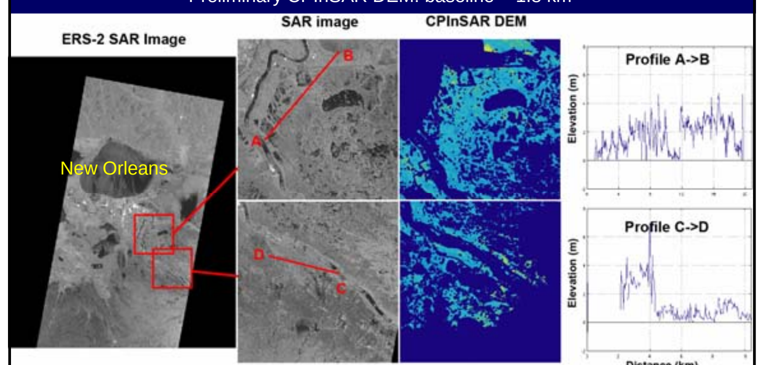
Technique development of Cross-Platform InSAR (CPInSAR)

- ENVISAT SAR sensor (ASAR) uses a slightly different radar frequency when compared to the ERS-2 SAR sensor.
- Accordingly ASAR data can not be combined with ERS-2 data via conventional InSAR technique.
- A technique, called cross-platform InSAR (CPInSAR) is being developed to manipulate SAR signals from two different sensors to generate a DEM.
- Under favorable imaging geometry conditions and terrain types, the accuracy of the CPInSAR-derived DEM can reach tens of centimeters - better than SRTM and comparable to Lidar.

CPInSAR DEM

30-minute Repeat-Pass InSAR

Preliminary CPInSAR DEM: baseline = 1.8 km



Kwoun and Lu, 2005

Emerging SAR/InSAR technologies

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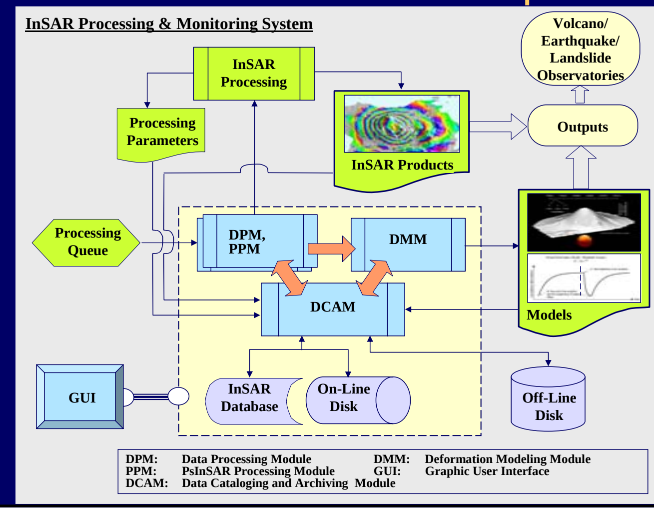
InSAR Future: from research to operation



Lu et al In prep 2005

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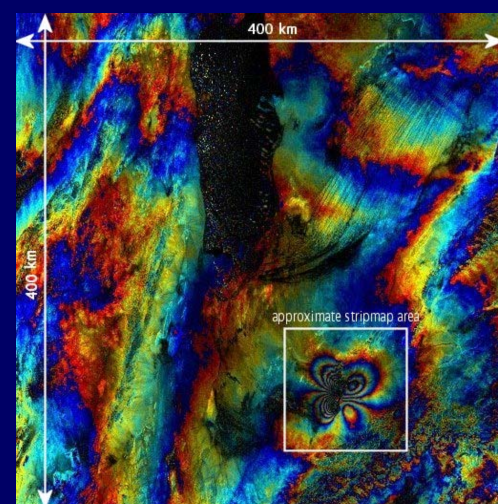
ScanSAR InSAR



SARMAP, 2004

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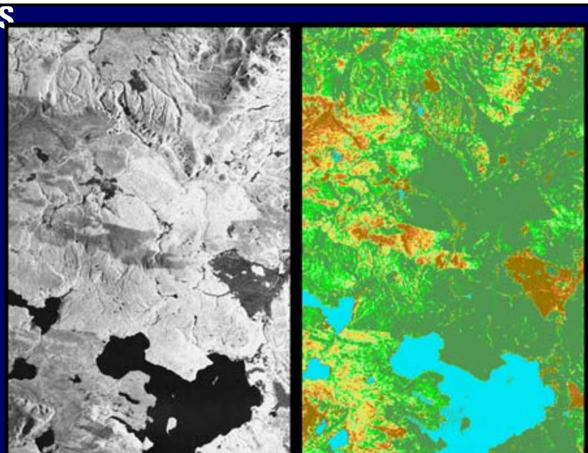
USGS Polarimetric InSAR for Canopy Height Mapping

1. Develop an optimization procedure to maximize the interferometric coherence between two polarimetric radar images to reduce the effect of baseline and temporal decorrelation on the interferogram.

2. Develop a coherent target decomposition approach that separates radar backscattering returns coming from the canopy top, the bulk volume of the forest, and the ground surface. The difference of interferometric phase measurements then leads to the height difference between the physical scatterers possessing these mechanisms.

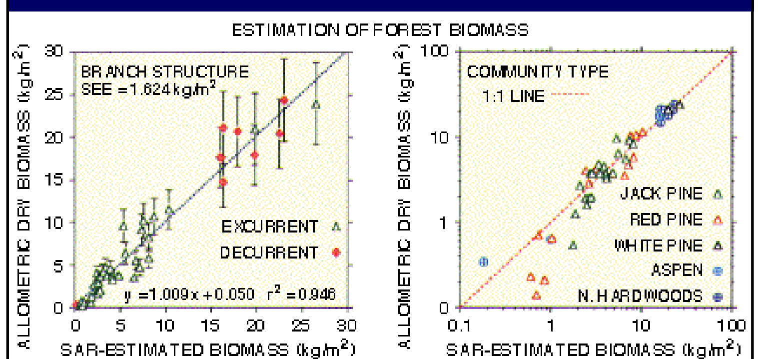
3. Develop a physical radar scattering model over different vegetation types to calculate the canopy height, the bare-earth topography, the mean volume extinction coefficient that is related to canopy density, and other canopy structural parameters based on measurements from a polarimetric InSAR image.

USGS

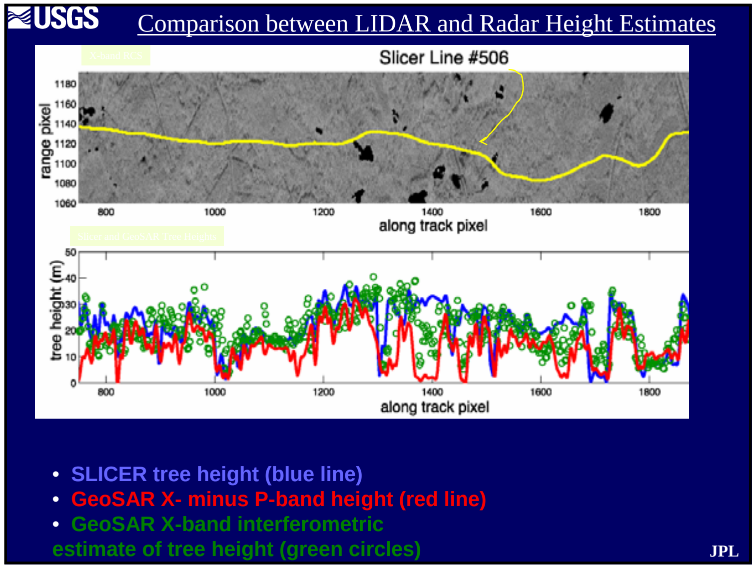


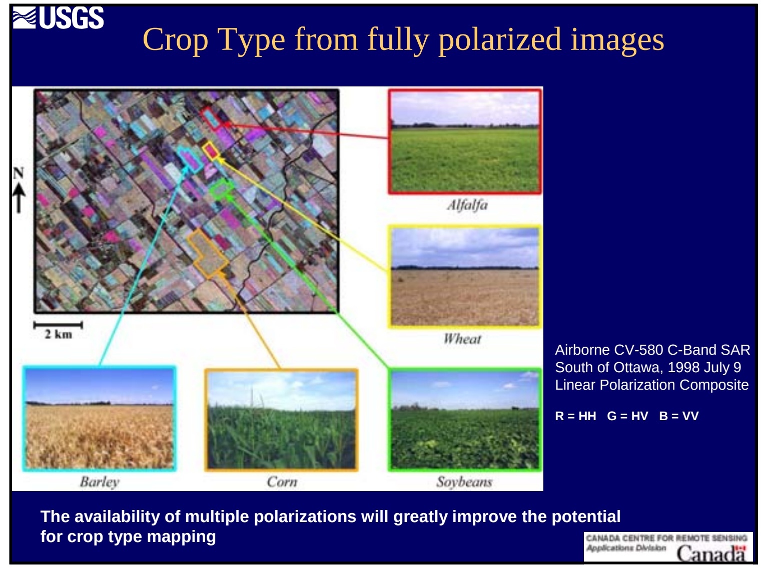
Mapping biomass at Yellowstone Park using SIR-C (C- and L- bands) SAR images taken in Oct. 1994. The biomass ranges from no biomass (blue) to non-forest areas with crown biomass of less than 4 tons per hectare (brown) to areas of canopy burn with biomass of between 4 and 12 tons per hectare (light brown). (Courtesy of JPL).

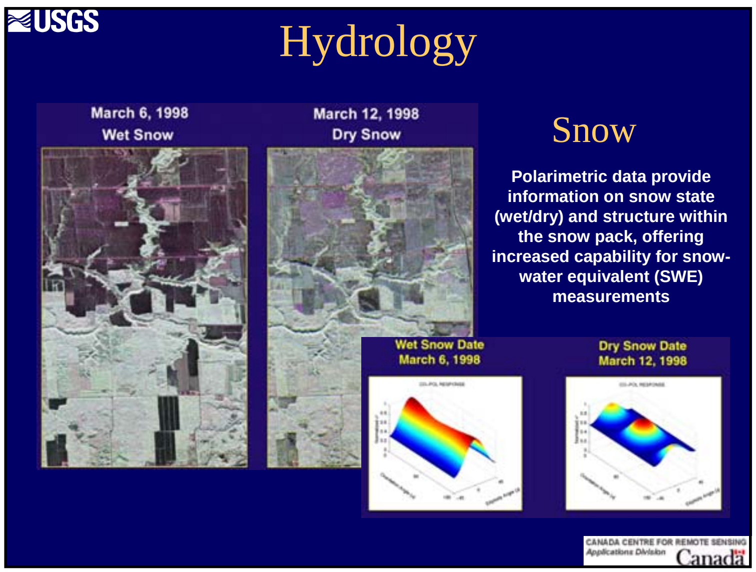
USGS Biomass Estimation from fully polarized SIR-C Data

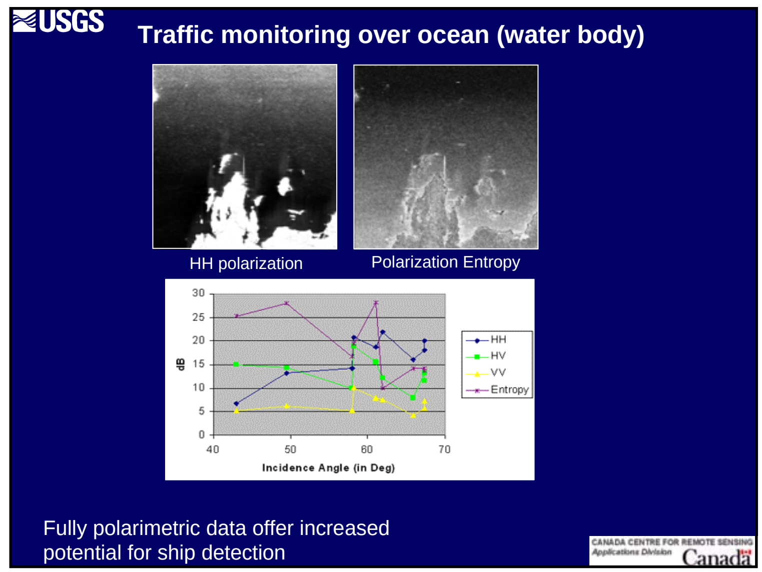


Dobson et al., 1995


USGS
Comparison between LIDAR and Radar Height Estimates
Slicer Line #506
range pixel
along track pixel
tree height (m)
along track pixel
• SLICER tree height (blue line)
• GeoSAR X- minus P-band height (red line)
• GeoSAR X-band interferometric estimate of tree height (green circles)
JPL


USGS
Crop Type from fully polarized images
N
2 km
Alfalfa
Wheat
Barley
Corn
Soybeans
Airborne CV-580 C-Band SAR
South of Ottawa, 1998 July 9
Linear Polarization Composite
R = HH G = HV B = VV
The availability of multiple polarizations will greatly improve the potential for crop type mapping
CANADA CENTRE FOR REMOTE SENSING
Applications Division
Canada


USGS
Hydrology
March 6, 1998
Wet Snow
March 12, 1998
Dry Snow
Snow
Polarimetric data provide information on snow state (wet/dry) and structure within the snow pack, offering increased capability for snow-water equivalent (SWE) measurements
Wet Snow Date
March 6, 1998
Dry Snow Date
March 12, 1998
CANADA CENTRE FOR REMOTE SENSING
Applications Division
Canada


USGS
Traffic monitoring over ocean (water body)
HH polarization
Polarization Entropy
dB
Incidence Angle (in Deg)
HH
HV
VV
Entropy
Fully polarimetric data offer increased potential for ship detection
CANADA CENTRE FOR REMOTE SENSING
Applications Division
Canada

Finally, …

The L-band ALOS PALSAR

is coming to life in January 2006!

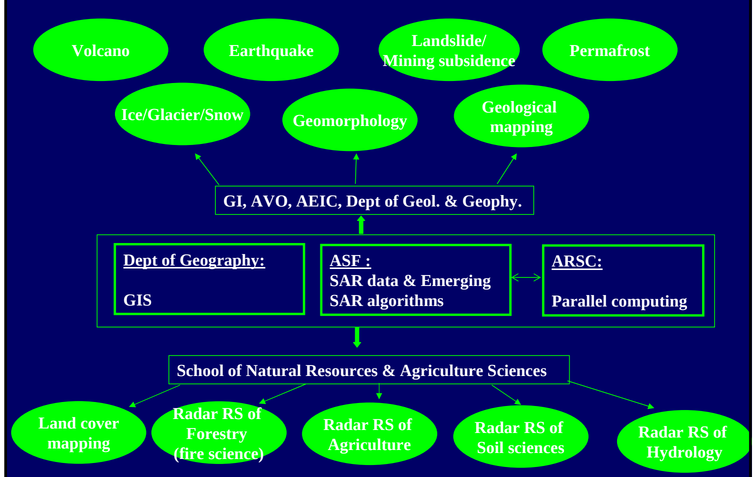
Emerging L-Band Capabilities

- L-band penetrates into vegetation
  - Land cover classification
  - Biomass estimation
  - Wetland monitoring
- Interacts with mechanically more stable parts of vegetation canopies
  - Increased interferometric coherence
  - Differential interferometry on global scale
  - Also better coherence over snow and ice
- Sea surface returns less sensitive to wind
  - Shallow Water Bathymetry

Emerging L-Band Capabilities

- L-band PALSAR provides capabilities unobtainable from existing C-band SARs
  - L-band PALSAR avoids much of the temporal decorrelation that plagues C-band systems over vegetated regions
  - Can measure water levels in wetlands to a couple centimeters (everglades etc.)
  - Fully polarized PALSAR improves biomass mapping
  - Fully polarized PALSAR maps soil moisture at a spatial resolution not achievable from optical imagery

A Road Map - New SAR Era at UAF



USGS

In the past decade, InSAR/SAR was in the hands of solid Earth sciences!

In the next decade, InSAR belongs to sciences of natural resources!

Let's work hand-by-hand, to face the challenges, and to have fun!