Groundswell: Use of Imaging Radar to Detect Groundwater Withdrawal and Recharge

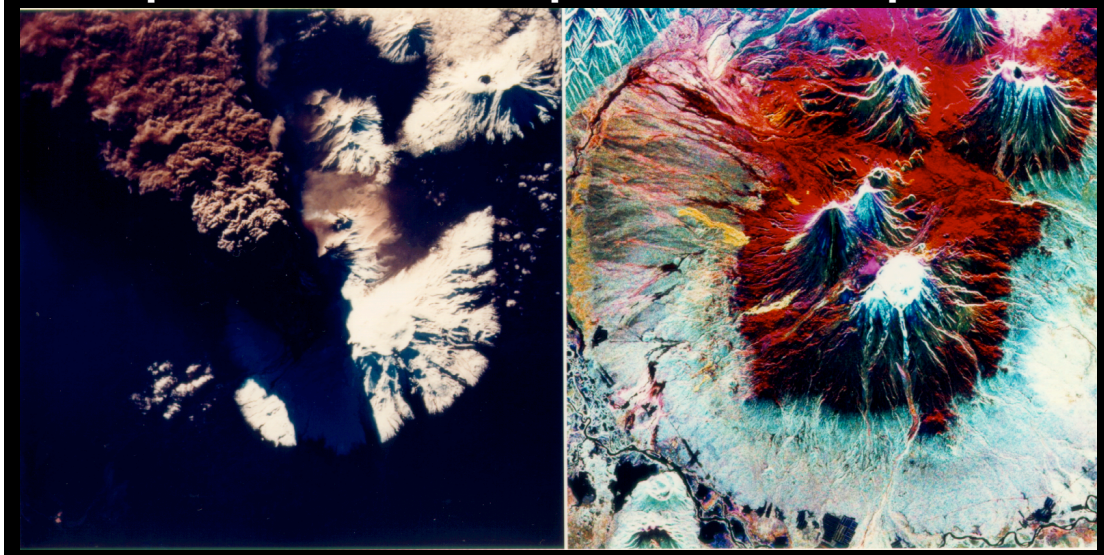
Tom G Farr
Jet Propulsion Laboratory
tom.farr@jpl.nasa.gov

Groundwater from Space

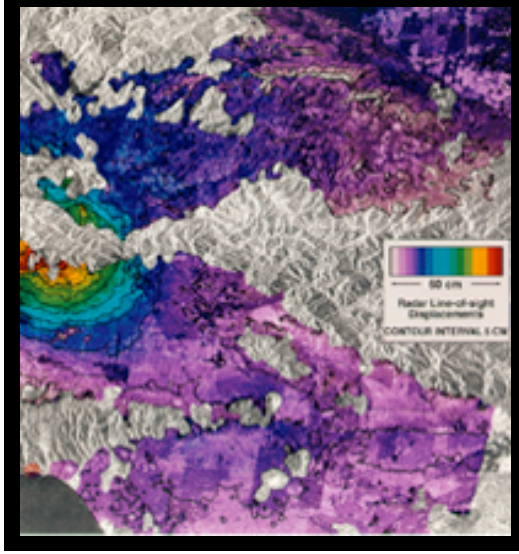
- Groundwater is becoming a more important part of water resources
- But knowledge of the groundwater level is not uniformly available
- Wells provide some monitoring capability, but there are political and practical difficulties
- Imaging radar interferometry can provide information on groundwater levels by measuring surface deformation caused by withdrawal and recharge of aquifers
- This can be done from space, now, and the US is planning to orbit a satellite that will provide even better information

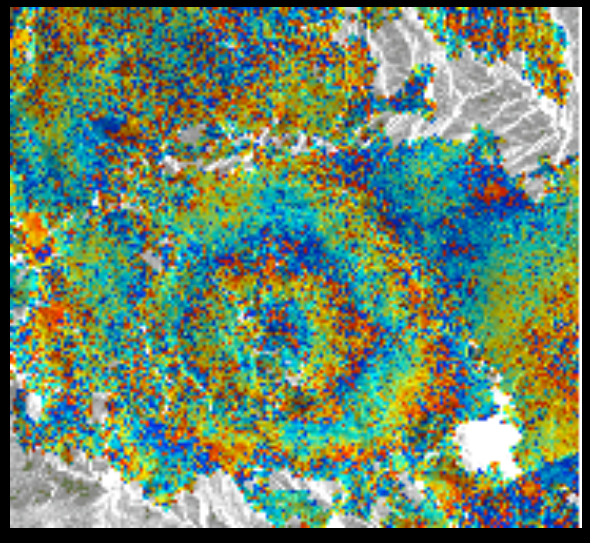
Key Attributes of Synthetic Aperture Radar (SAR) Data

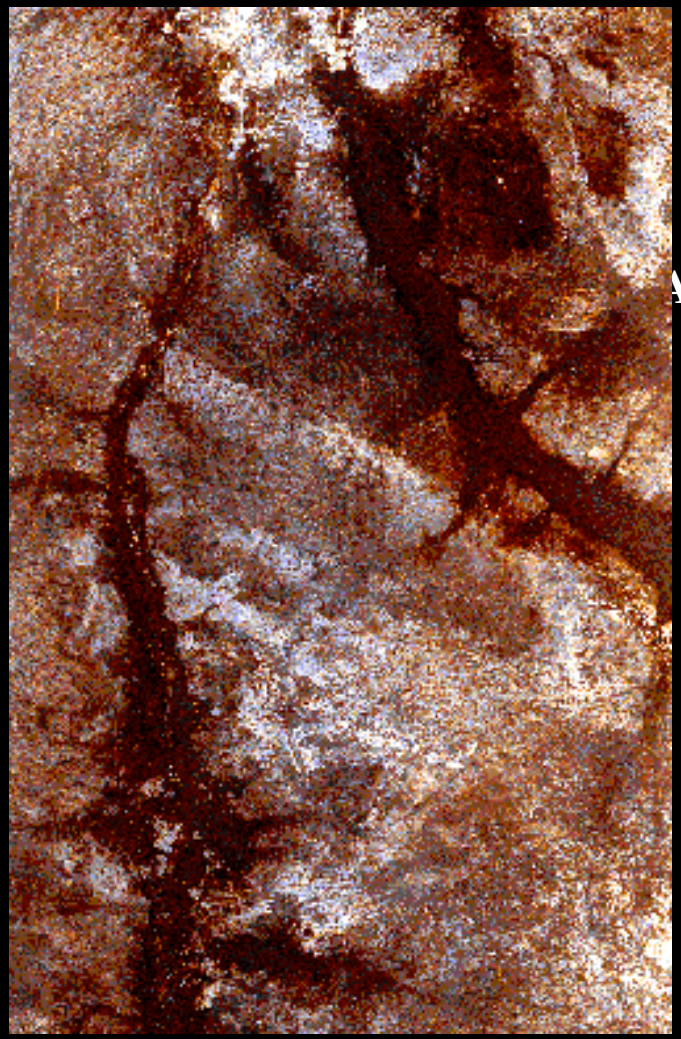
Repeatable multitemporal data independent of weather or sun illumination



Phase coherence for interferometry

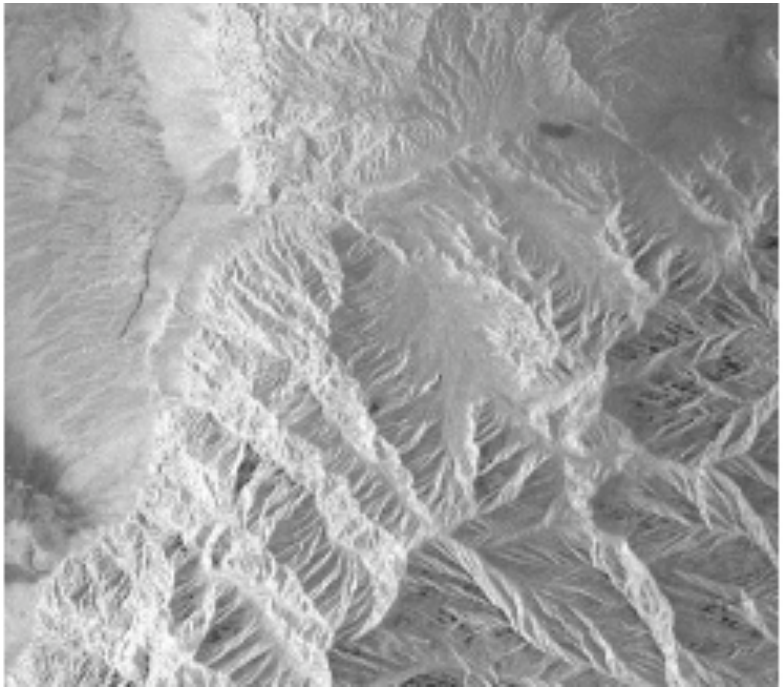




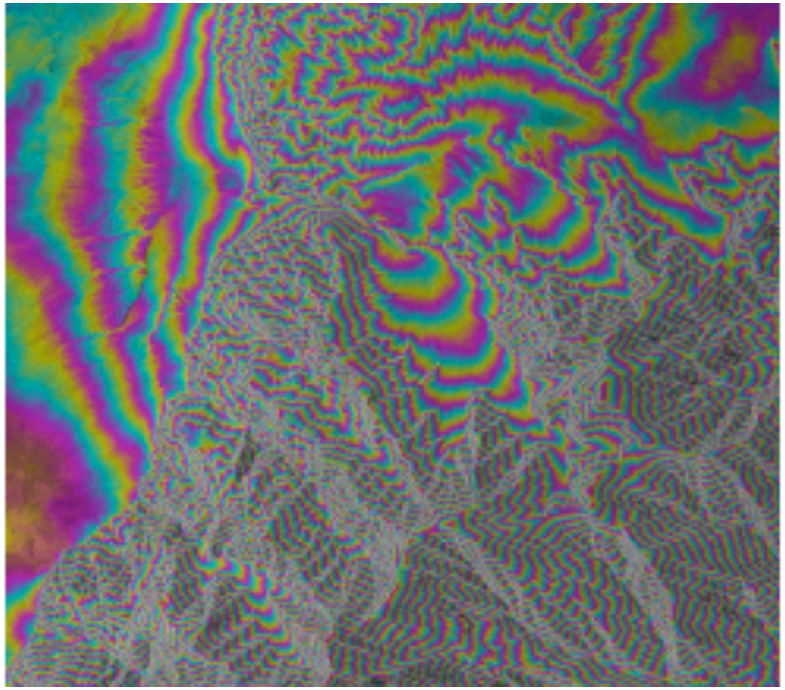


Physical information about surfaces and volumes

Radar Interferometry:
Topography Example



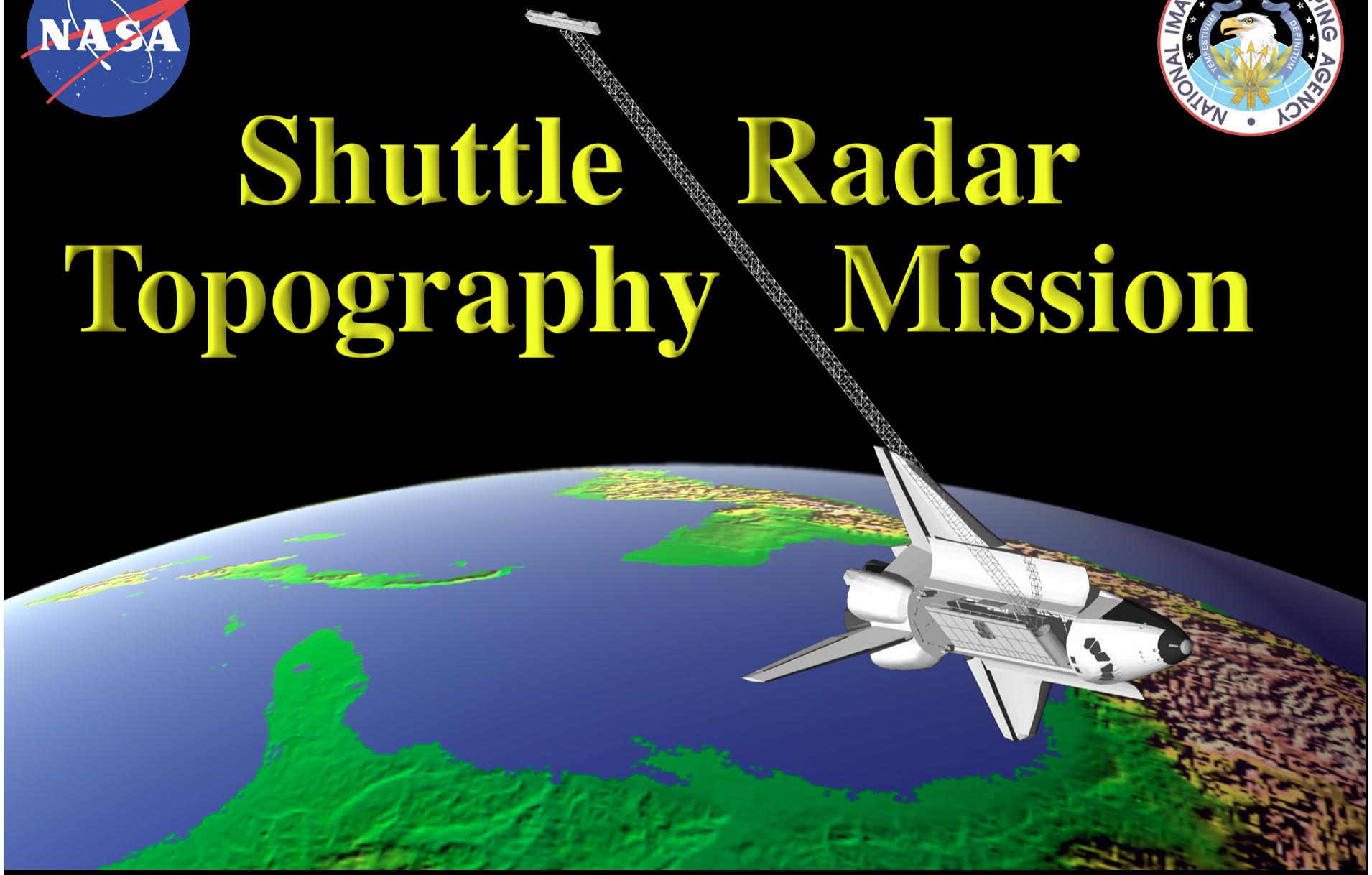
Standard Radar Image



Interference fringes follow the topography

One cycle of color represents 1/2 wavelength of path difference

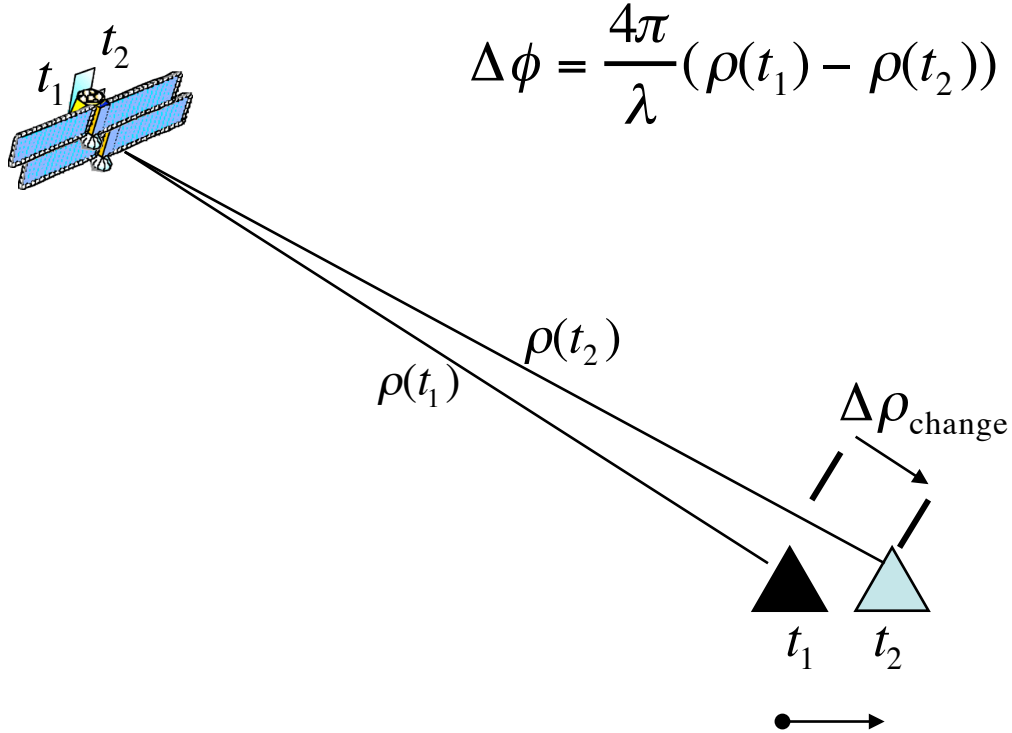
Shuttle Radar Topography Mission



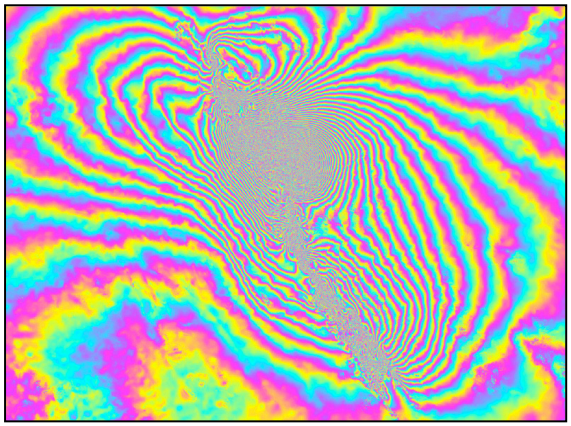
Deformation Interferometry

When two observations are made from the same location in space but at different times, the interferometric phase is proportional to any change in the range of a surface feature directly.

$$\Delta\phi = \frac{4\pi}{\lambda}(\rho(t_1) - \rho(t_2)) = \frac{4\pi}{\lambda}\Delta\rho_{\text{change}}$$



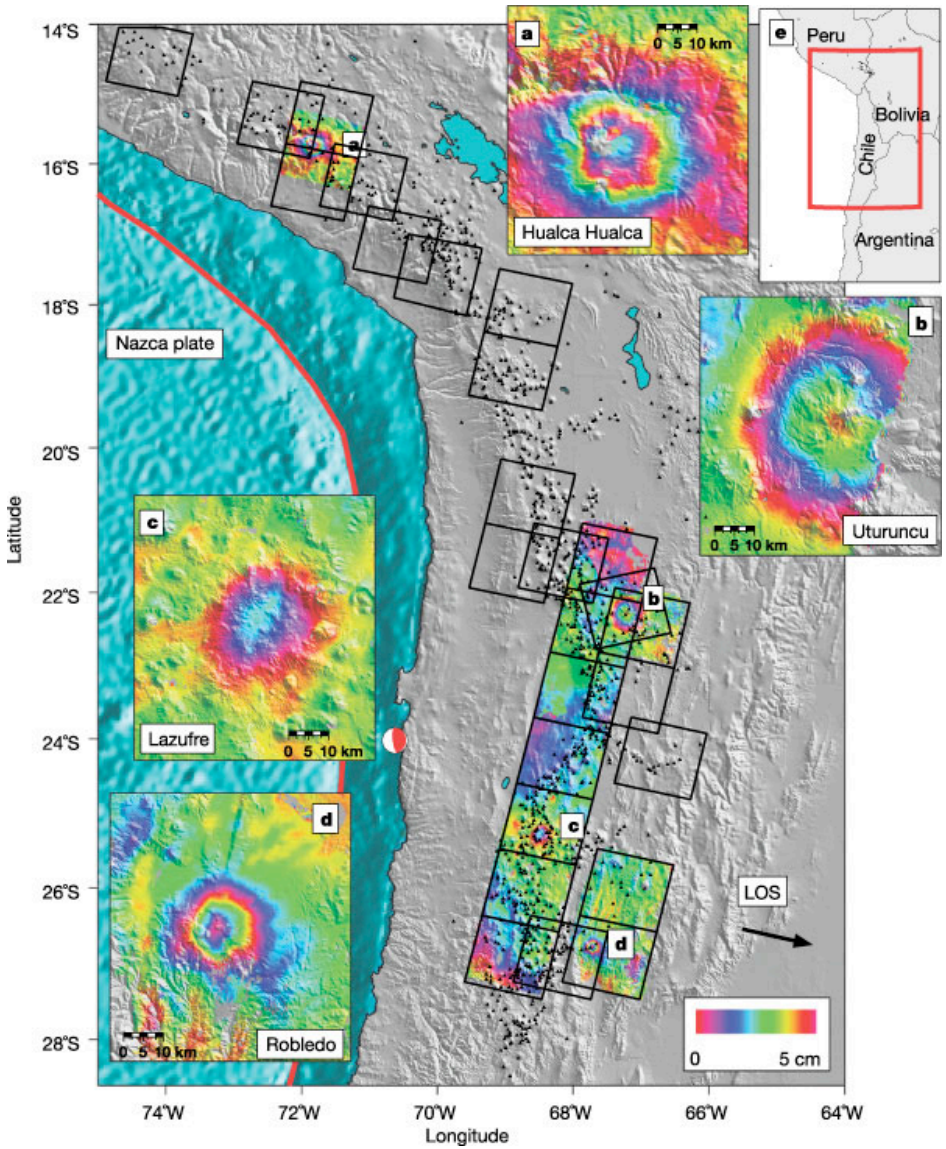
Surface Deformation Phase



Landers Earthquake,
Mojave Desert, 1992

Peltzer, JPL

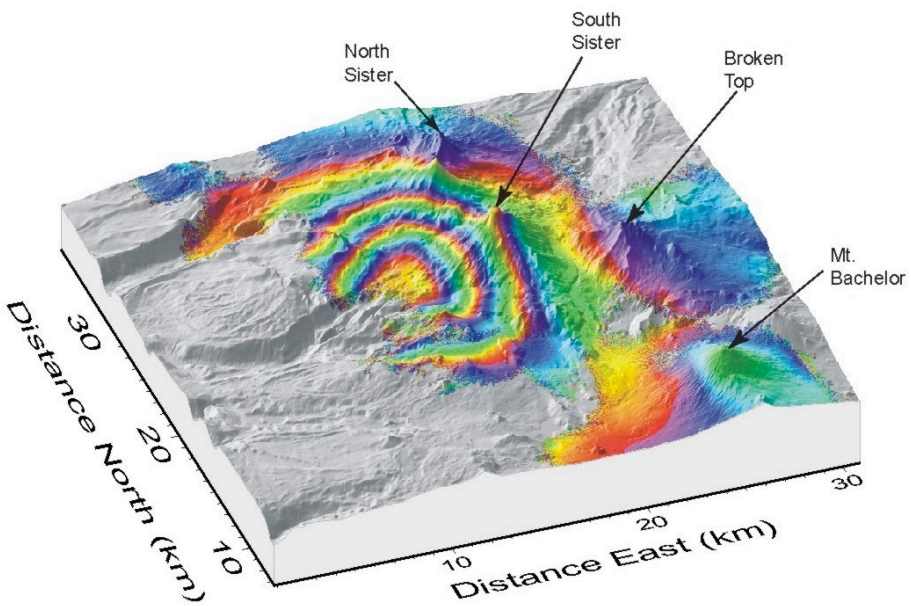
Volcano Monitoring



Andes

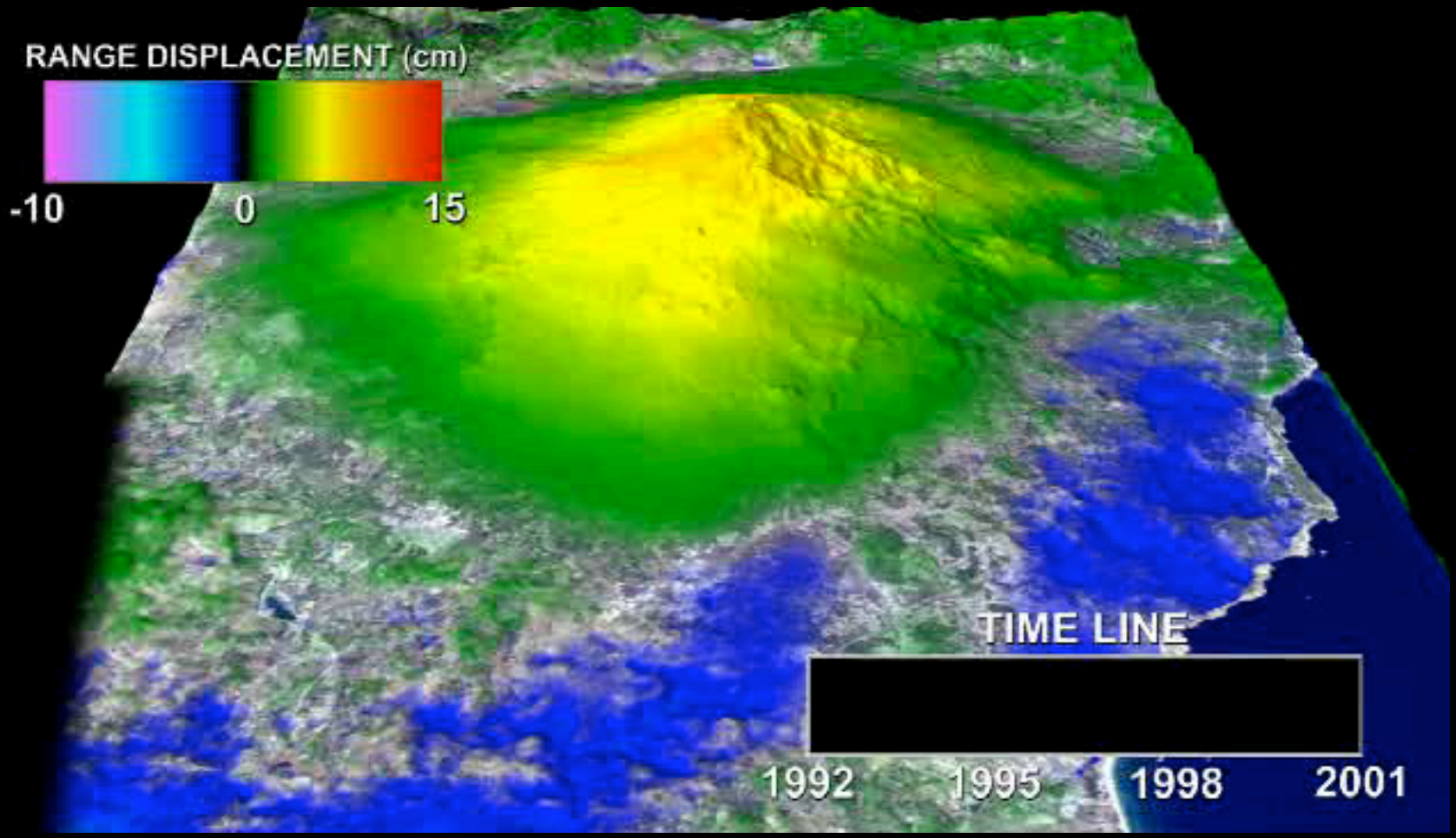
Pritchard and Simons, 2002

3 Sisters, Oregon



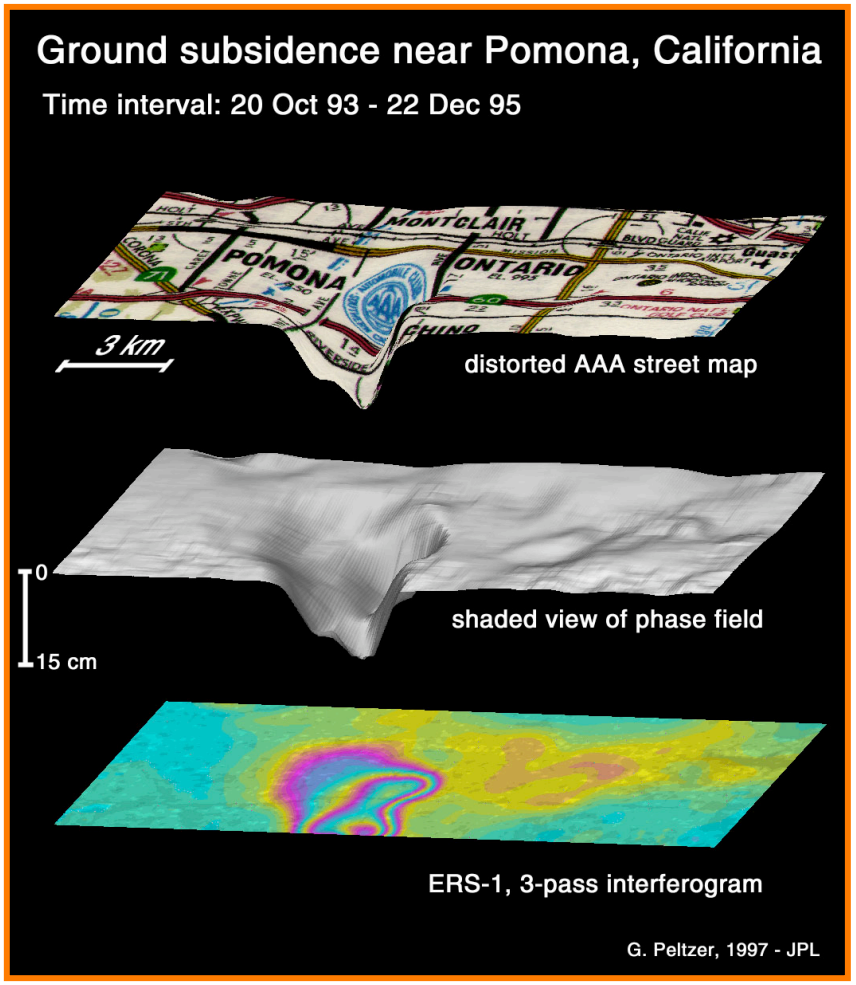
C. Wicks, USGS

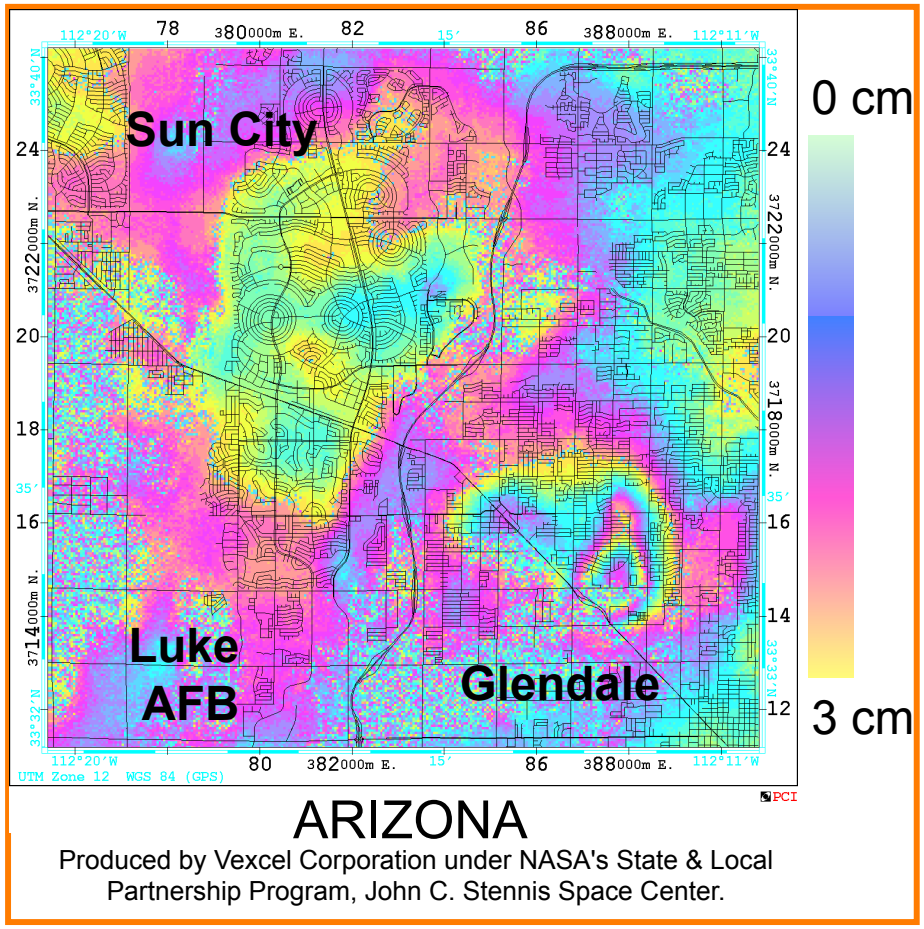
Inflation, Deflation, and Eruption of Mount Etna

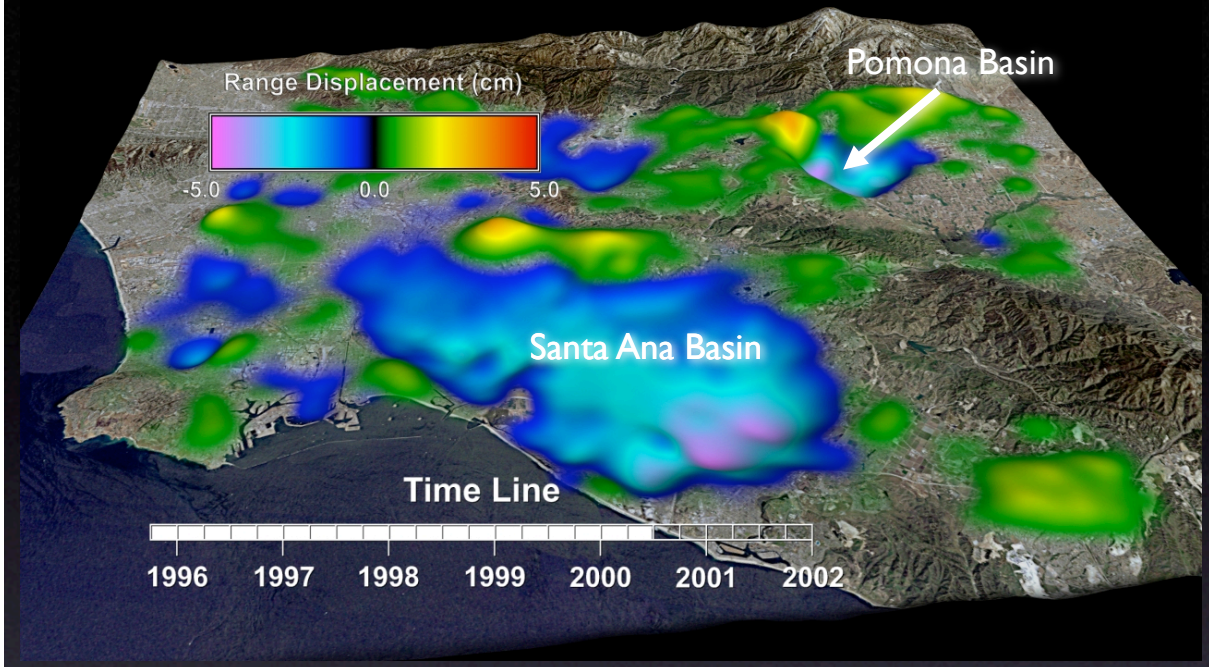


Land Subsidence

Measurement of crustal deformation is also used to detect land subsidence: sinking of the land due withdrawal of water and oil.







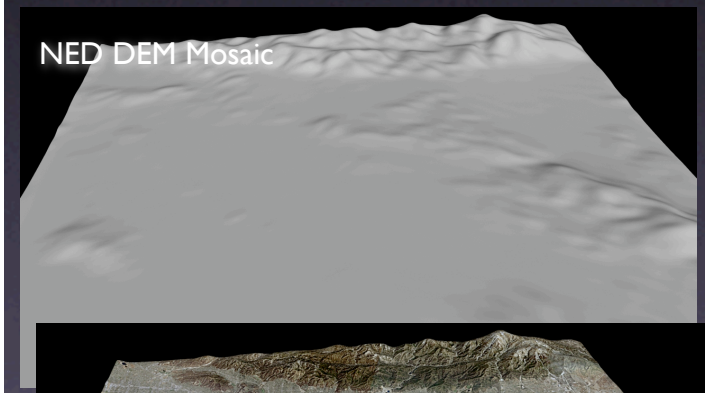
Case Study: Visualization of Ground Deformation Related to Southern California Ground Water Basins

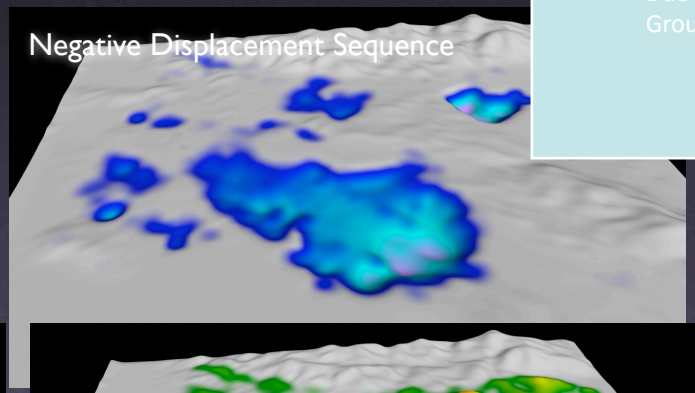
Deformation Time-Series Derived from Radar Interferometry

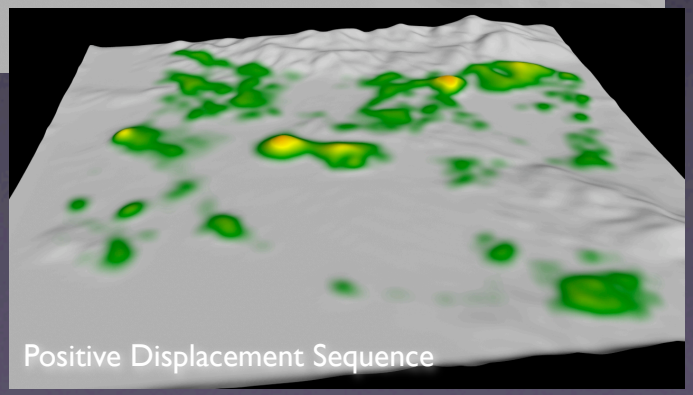
- Sequence of 42 Interferograms Generated from ERS-1/ERS-2 Data
- 2270 Animation Frames Produced by Linear Interpolation Between Pairs of Interferograms

Ground Water-Related Deformation Observed on Two Different Time Scales

- Net Subsidence of the Santa Ana and Pomona Basins Over 6-yr Study Period Attributed to Compaction of Sediments during Discharge
- Annual Fluctuations in Subsidence and Uplift Due to Seasonal Discharge and Recharge of Ground Water Basins







INSAR data courtesy of P. Lundgren, Jet Propulsion Laboratory

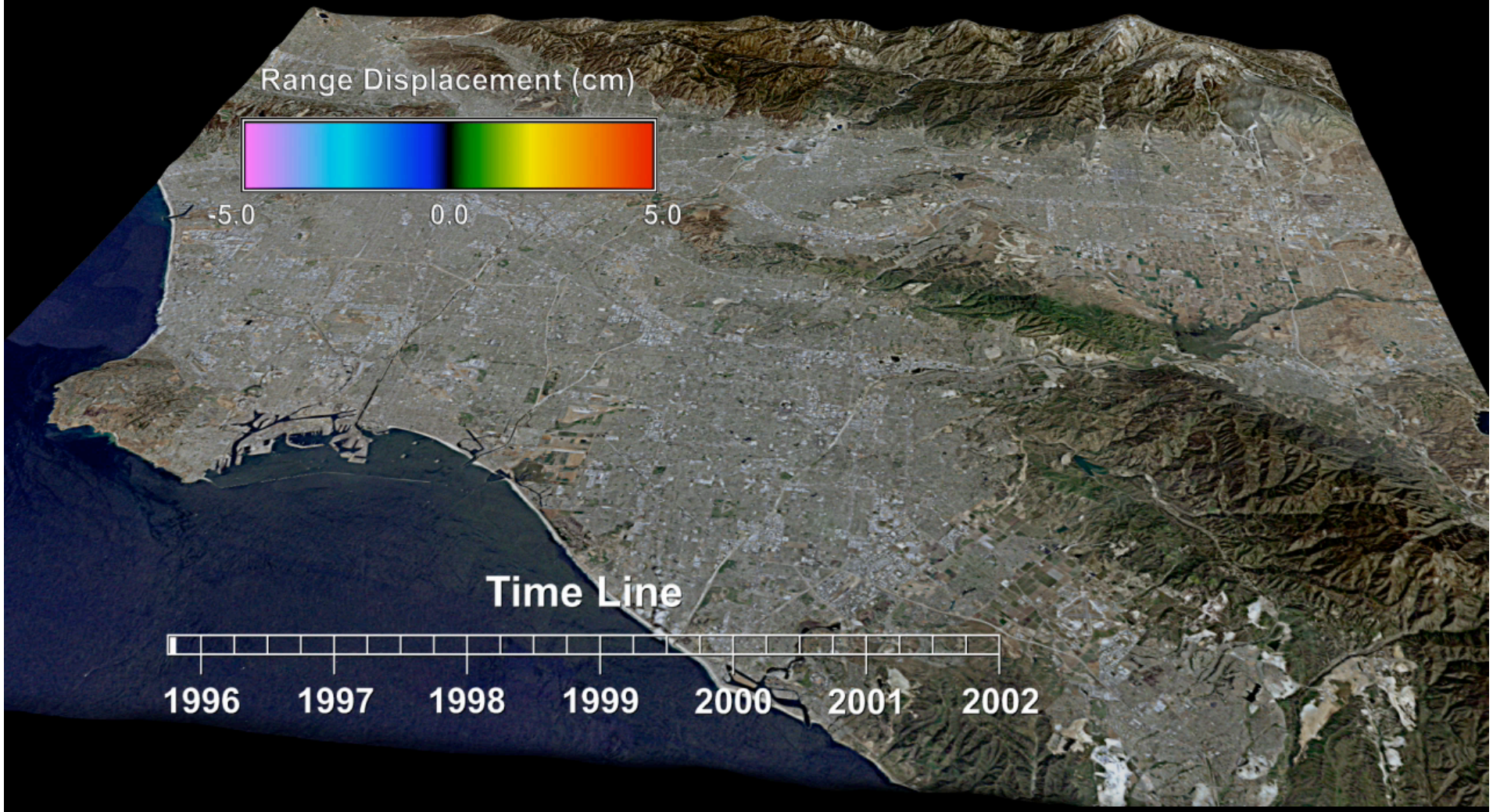
References:

Lanari et al., Geophysical Research Letters, V.31, L23613, doi:10.1029/2004GL021294, 2004

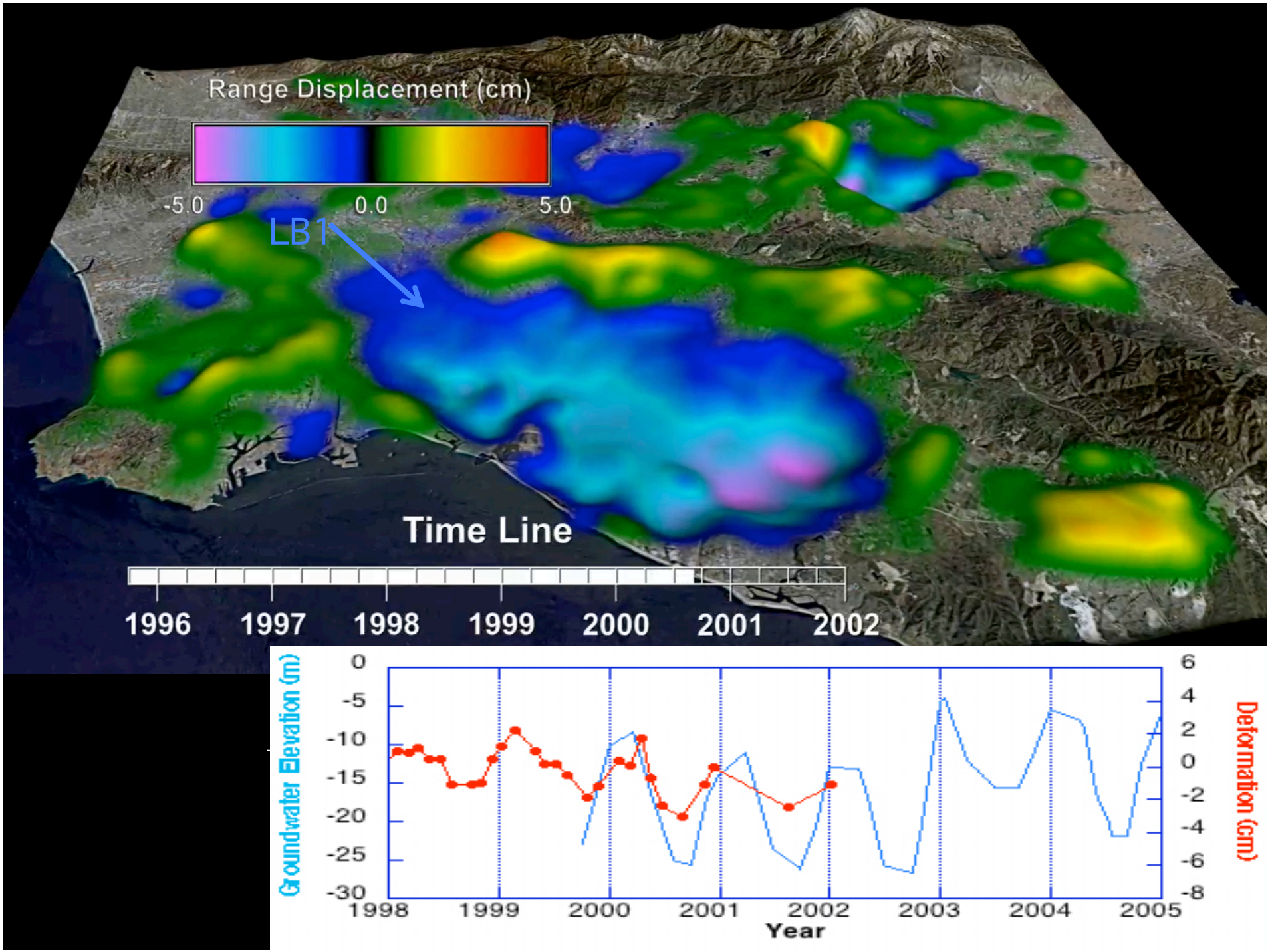
Argus et al., Journal of Geophysical Research, V.110, B04401, doi: 10.1029/2003JB002934, 2005

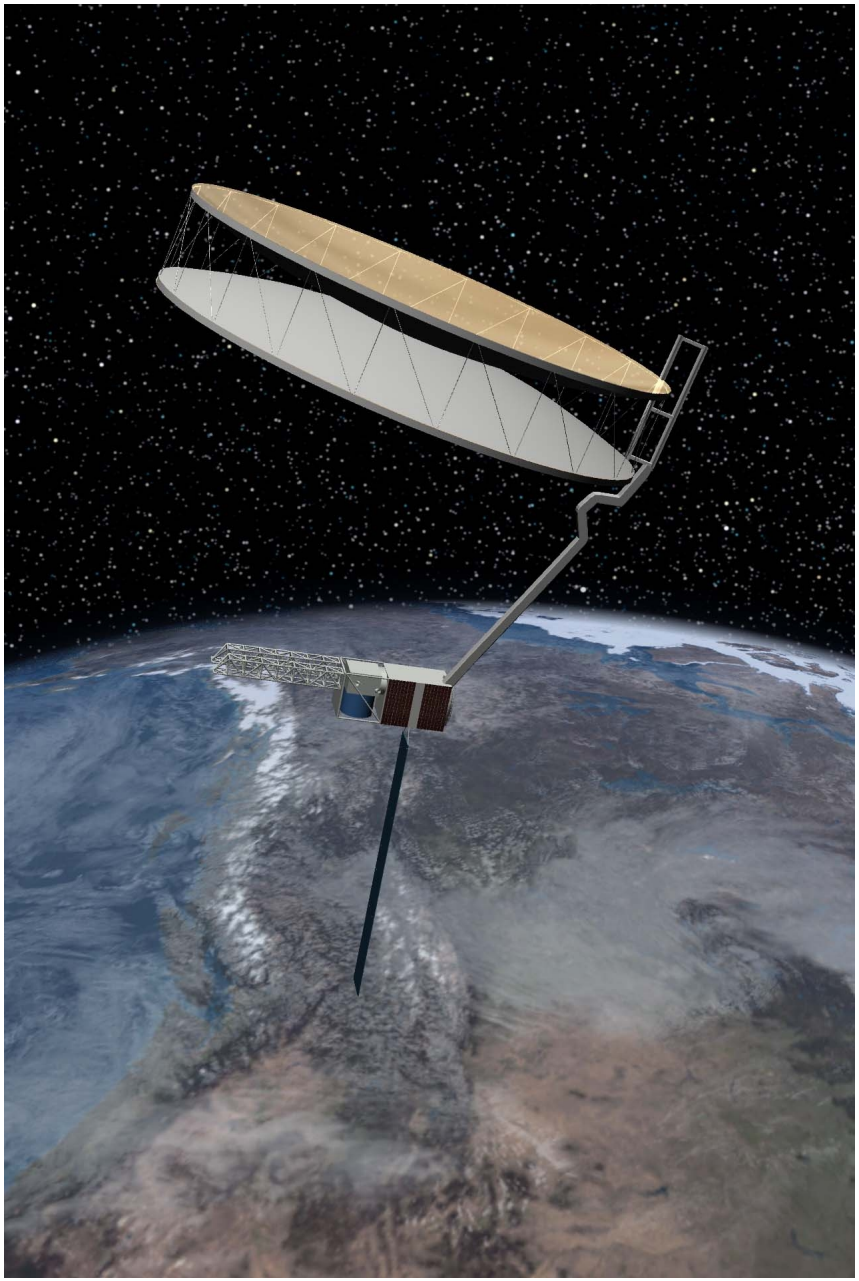
King et al., Journal of Geophysical Research, V.112, B03409, doi:10.1029/2006JB004448, 2007

Monitoring LA Basin



Paul Lundgren, Vince Realmuto, JPL

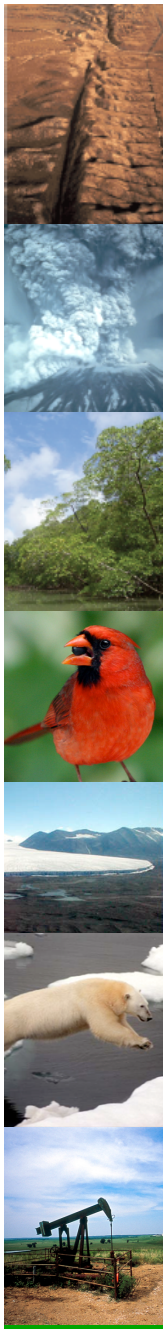

Range Displacement (cm)
-5.0
0.0
5.0
LB1
Time Line
1996
1997
1998
1999
2000
2001
2002
Groundwater Elevation (m)
0
-5
-10
-15
-20
-25
-30
Deformation (cm)
6
4
2
0
-2
-4
-6
-8
1998
1999
2000
2001
2002
2003
2004
2005
Year



Deformation, Ecosystem Structure, & Dynamics of Ice (DESDynI) Mission

1. Interferometric Synthetic Aperture Radar (InSAR)
2. Infrared LiDAR

Launch≈Jan 2017
Resolution 25m



DESDynI Meets Broad Scientific Needs

Meets the needs of the largest portion of the science community of any of the recommended decadal survey missions

Deformation	Ecosystems	Ice Masses	Subsurface Reservoirs
Earthquakes Probability, aftershocks, stress transfer	**Aboveground biomass** Carbon sources and sinks	**Ice Sheet Flow** Response of ice sheets and shelves to ocean and atmosphere	**Aquifers** Withdrawal and Recharge Subsidence
Volcanoes Volume, depth, and migration of magma chamber	**Changes in carbon stocks** Interaction between vegetation and atmosphere	**Glaciers** Response to atmosphere	**CO_2 Sequestration** Subsurface migration
Landslides Detect preslip	**Biodiversity** Habitat structure	**Sea Ice** Interaction between ocean and atmosphere	**Oil Reservoirs** Subsidence, pipe breakage

Key Challenges

Additional Science Benefits

Monitoring Levies and Subsidence in the Sacramento-San Joaquin Valley using UAVSAR

Cathleen Jones
Jet Propulsion Laboratory
cathleen.e.jones@jpl.nasa.gov
818 393 1048

NASA Funded Project: Monitoring Levees and Subsidence in the Sacramento-San Joaquin Delta using UAVSAR

PARTNERS: Jet Propulsion Laboratory *(P.I. Cathleen Jones, Scott Hensley)*, ***California Department of Water Resources*** (Joel Dudas), ***USGS*** *(Gerald Bawden)*, ***HydroFocus*** *(Steve Deverel)*

1. **Risk Assessment & Disaster Management (Levees)**

   Assess changes in the condition and integrity of the levees on a monthly basis by measuring small-scale changes in the levee positions using DifInSAR.

   Support emergency response to levee threats and failures.

   Provide data to inform Delta Emergency Response Plan for a major earthquake in the San Francisco area.

2. **Water Resource Management (Subsidence/Levees)**

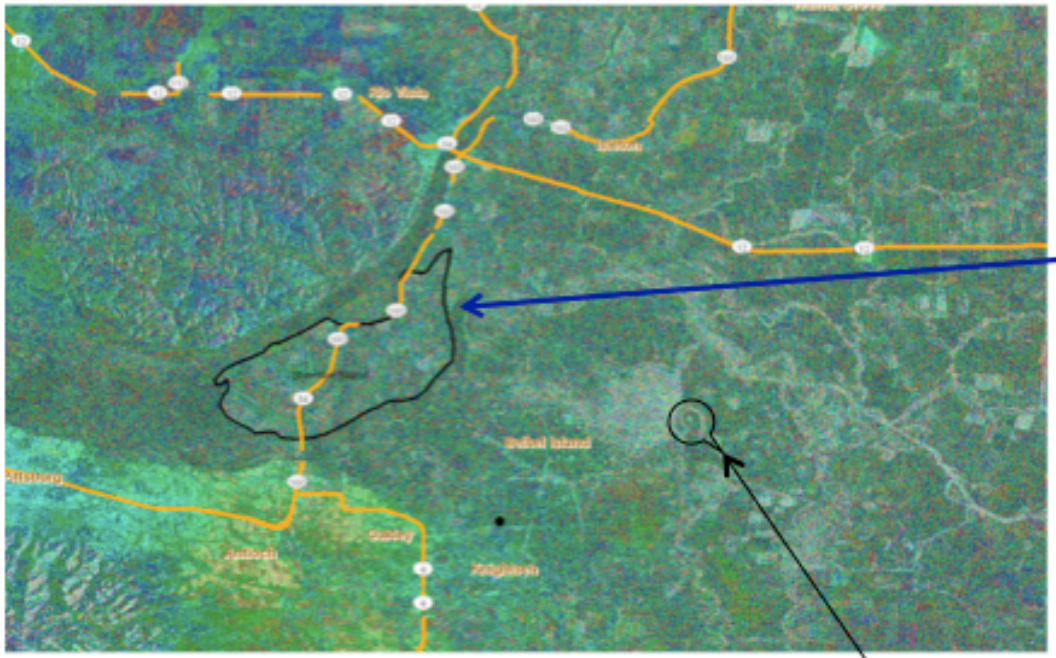
   Short Term: Support decisions on the allocation of funds for levee repairs and upgrades by monitoring levee conditions across the entire Sacramento-San Joaquin Delta in a comprehensive and consistent manner.

   - independent and verifiable source of information with the spatial extent needed to cover the 1100 miles of levees within the Delta

   - temporal frequency required to detect changes indicative of potential levee failure

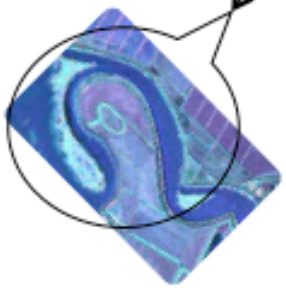
   Long Term: Provide critical subsidence rate measurements needed to inform a viable long term solution to water management in the area.

CHALLENGE: Requires high resolution to resolve levees and sub-centimeter change detection capability.



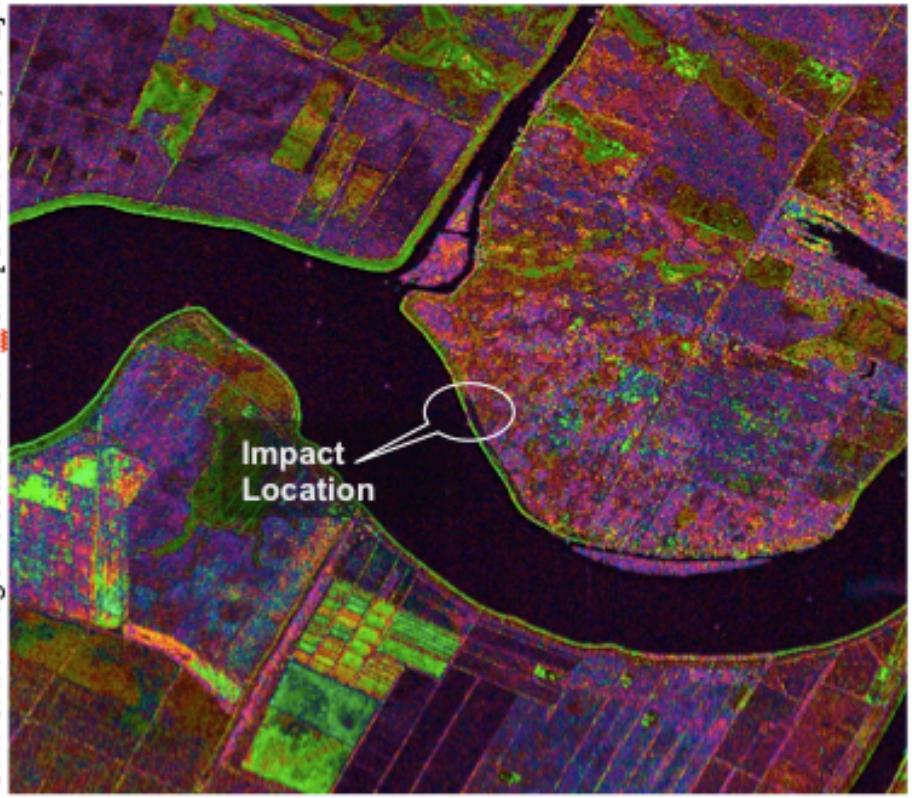
Satellite image of the Delta – resolving the levees is not feasible.

… compare feature resolution to that of UAVSAR



UAVSAR in 2009: Bradford Island levee monitoring

On August 28, 2009 a ship rammed the north levee on Bradford Island. This image was made from an interferogram between UAVSAR data collected on July 17 and Sept. 10, so evidence of the impact and repair are seen in the data. We have been using the data from this project to monitor the repaired levee for changes since the damage occurred.



UAVSAR image resolution 6m x 6m [C. E. Jones, JPL]

Bradford Island north levee damage, Sept. 2009 [photo courtesy of Ca. DWR]

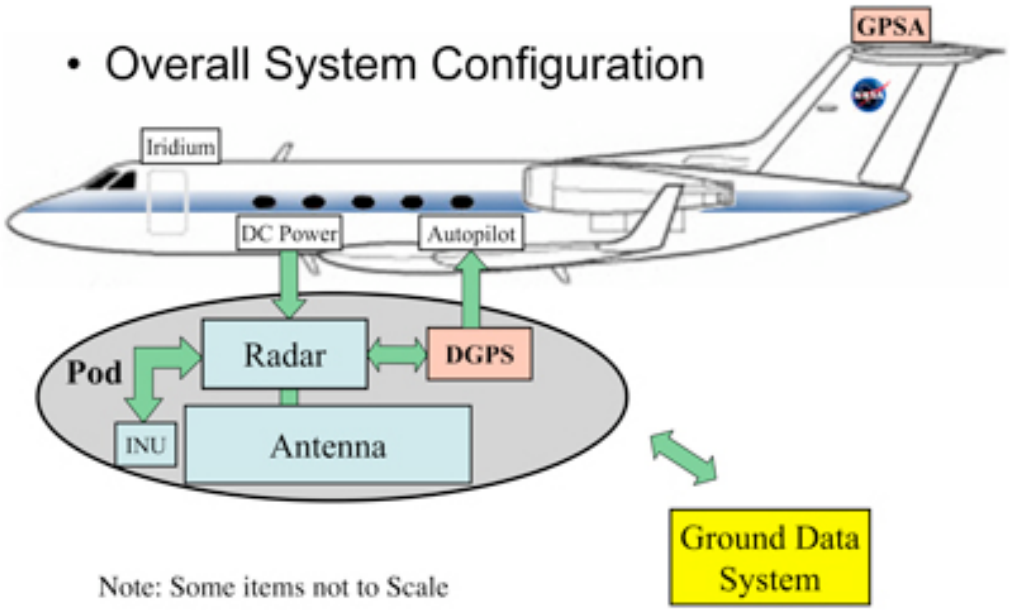
An Emerging Future for Remote Sensing

Dean Wiberg
Commercial Program Office
Jet Propulsion Laboratory (JPL)
818 354 5724
dean.v.wiberg@jpl.nasa.gov

An emerging trend in science data requirements for California Water is higher spatial and temporal resolution for improved system monitoring and process control
(e.g. Bay Delta, Owens Lake)

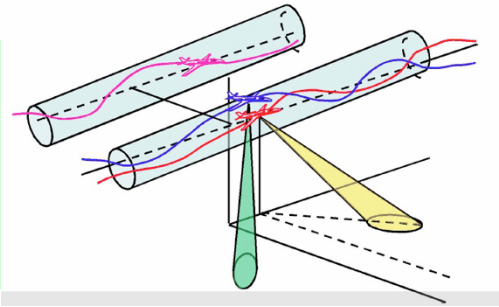
- Low Earth Orbit (LEO)=100-1240 miles
- Typical Space Shuttle Altitude ≈210 miles

The relationship for pixel size (resolution) to altitude is basically 1:1
The same instrument with a resolution of 30 meters at 210 miles will have a resolution of 1.3 meters at 50,000 feet and 0.54 meters at 20,000 feet



A Grumman Gulfstream III (G-III) business jet has been modified and instrumented by NASA's Dryden Flight Research Center

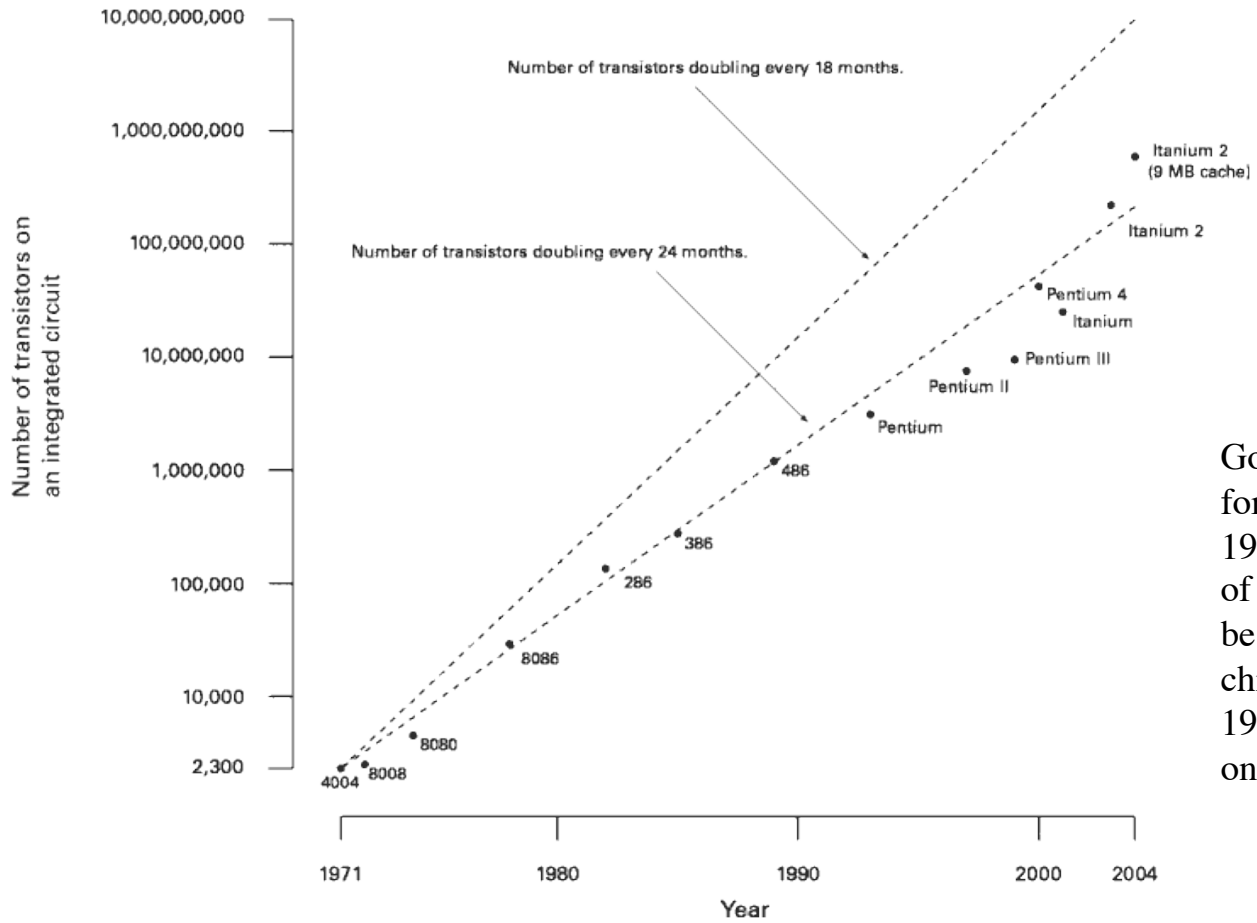
- Nominal altitude≈45,000 ft
- Mass≈950 lb
- Resolution≈2 m
- Flight control tube≈10 m



UAVSAR Pod

Source:http://uavsar.jpl.nasa.gov/overview.html

Moore's Law



Gordon Moore is widely known for "Moore's Law," in which in 1965 he predicted that the number of components the industry would be able to place on a computer chip would double every year. In 1975, he updated his prediction to once every two years.

Moore's law has allowed similar improvements in instrument size, mass and power enabling the same instrument performance in much smaller packages (subject to aperture requirements).

Emerging availability and regulatory allowance of UAV platforms in the Civil Air Space will provide increased remote sensing spatial and temporal resolution at reduced cost

1) Application of Moore's law will continue to reduce instrument size (MEMS and nanotech systems are emerging routinely)

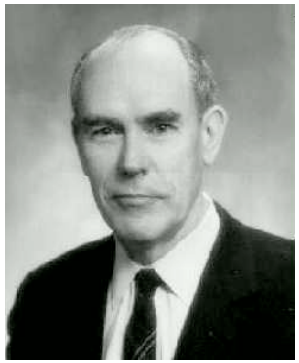
2) **"Things tend to cost what they weigh"**
(Ivan Sutherland, Fellow Sun Microsystems, Chairman Computer Science, Caltech)

3) United States has 42 manufacturers of UAV's offering 142 models
(Aerospace America (AIAA), Apr 2009)

4) "…roughly twice as many unmanned as manned aircraft" are deployed in the Middle East (Iraq, Afghanistan, etc)
(Aerospace America (AIAA), Apr 2009)

5) As the conflicts in the Middle East are resolved, many surplus systems and operators are going to be available

6) Use of UAV's in the US airspace will essentially become like any other civil flight by about 2014.
(Jerry Lockenour, Director of Technology Development for Aerospace systems, Northrop Grumman)



Ivan Sutherland

Northrop Grumman Global Hawk

- Payload≈3000 lb
- Ceiling≈65,000 ft

Predator Ground Station

General Atomic Predator

- Payload≈750 lb
- Ceiling≈25,000 ft

Thermal Imager being loaded on NASA Predator for use in monitoring California wild fires

Delft University of Technology Dragonfly (Delfly)

- Wingspan≈15 cm (5.9 in)
- Mass≈3 gm (0.11 oz)
- Streaming video

Aerovironment Raven

- Payload≈1 lb
- Ceiling≈15,000 ft

Raven Ground Station

AAI Shadow

- Payload≈9 lb
- Ceiling≈17,000 ft

Lockheed High Altitude Airship (HAA)

- Payload≈500 lb (3500 lb)
- Ceiling≈60,000 ft (58,000 ft)
- Duration>30 days