The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2333-12

Workshop on Science Applications of GNSS in Developing Countries (11-27 April), followed by the: Seminar on Development and Use of the Ionospheric NeQuick Model (30 April-1 May)

11 April - 1 May, 2012

Remote Sensing Systems Integrated with GNSS for Monitoring and Measuring Changes for Natural Hazards

HOTHEM Larry Dalton

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USGS

science for a changing world

Earthquakes ★ Floods ★ Hurricanes ★ Landslides ★ Tsunamis ★ Volcanoes ★ Wildfires

Remote Sensing Systems Integrated with GNSS for Monitoring and Measuring Changes for Natural Hazards

Larry D. Hothem - U. S. Geological Survey, Reston, Virginia USA

Workshop on Science Applications of GNSS in Developing Countries
The Abdus Salam International Center for Theoretical Physics

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U.S. Department of the Interior

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- **David Applegate, Ph.D.**
  - Associate Director for Natural Hazards, USGS

and many others

USGS

USGS Mission Areas

- Climate and Land Use Change
- Core Science Systems
- Ecosystems
- Energy and Minerals
- Environmental Health
- Natural Hazards
- Water

USGS

Climate and Land Use Change

http://www.usgs.gov/climate_landuse/

The USGS undertakes scientific research, monitoring, remote sensing, modeling, synthesis, and forecasting to address the effects of climate and land use change on the Nation's resources. The resulting research and products are provided as the scientific foundation upon which policymakers, natural resource managers, and the public make informed decisions about the management of natural resources on which they and others depend.

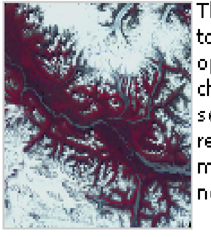
Help shape the future of USGS science by weighing in on our Science Strategy planning process.

Climate and Land Use Change Programs

Carbon Sequestration

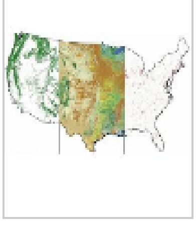
Scientists at the U.S. Geological Survey (USGS) are working to assess both the potential capacities and the potential limitations of the various forms of carbon sequestration and to evaluate their geologic, hydrologic, and ecological consequences. In accordance with the Energy Independence and Security Act of 2007, the USGS has developed scientifically based methods for assessment of biologic and geologic carbon sequestration.

Earth Resources Observation and Science Center (EROS)



The USGS Earth Resources Observation and Science Center (EROS) contributes to the Climate and Land Use Change Mission Area through research and operational activities that enable the understanding of local to global land change. The EROS multidisciplinary staff uses their unique expertise in remote sensing-based science and technologies to carry out basic and applied research, data acquisition, systems engineering, information access and management, and archive preservation to address the Nation's most critical needs.

Geographic Analysis and Monitoring (GAM)

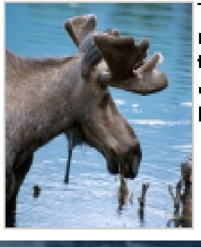


The goal of the USGS Geographic Analysis and Monitoring (GAM) Program is to understand the patterns, processes, and consequences of changes in land use, land condition, and land cover at multiple spatial and temporal scales, resulting from the interactions between human activities and natural systems.

Land Remote Sensing (LRS)

The Land Remote Sensing Program operates the Landsat satellites and provides the Nation's portal to the largest archive of remotely sensed land data in the world, supplying access to current and historical images. These images serve many purposes from assessing the impact of natural disasters to monitoring global agricultural production.

National Climate Change and Wildlife Science Center (NCCWSC)



The National Climate Change and Wildlife Science Center responds to the research and management needs of partners and provides science and technical support regarding the impacts of climate change on fish, wildlife and ecological process. The Center is taking the lead on establishing the Department of the Interior regional Climate Science Centers.

Research and Development Program (R&D)

The USGS Climate and Land Use Change Research and Development Program supports fundamental scientific research to: 1) understand processes controlling Earth system responses to global change over broad temporal and spatial scales; and 2) understand and model impacts of climate and land-cover change on ecosystems and other natural resources.

Land Remote Sensing Program

- **Satellite and airborne remote sensing (RS) systems**
  - providing geospatial information and data
- **RS data serve many purposes, such as:**
  - monitoring natural hazards,
  - assessing the impact of natural disasters,
  - monitoring global agricultural production, and
  - monitoring the impact of climate changes.
- **USGS operates the RS satellites Landsat**
  - Landsat 8 – scheduled for launch in January 2013
  - Free access to 40+ years of archived Landsat data

- **USGS archives RS data many sources**
  - current and historical

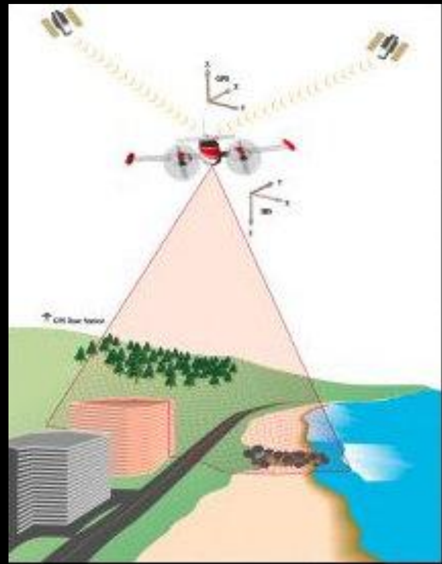
USGS Remote Sensing Technologies Project
Earth Resources Observation & Science (EROS) Center
http://eros.usgs.gov/

- Provide technical expertise and services
- Satellite digital imagery
- Aerial digital imagery
- Light Detection and Ranging (LiDAR) data
- Synthetic Aperture Radar (SAR) data

USGS

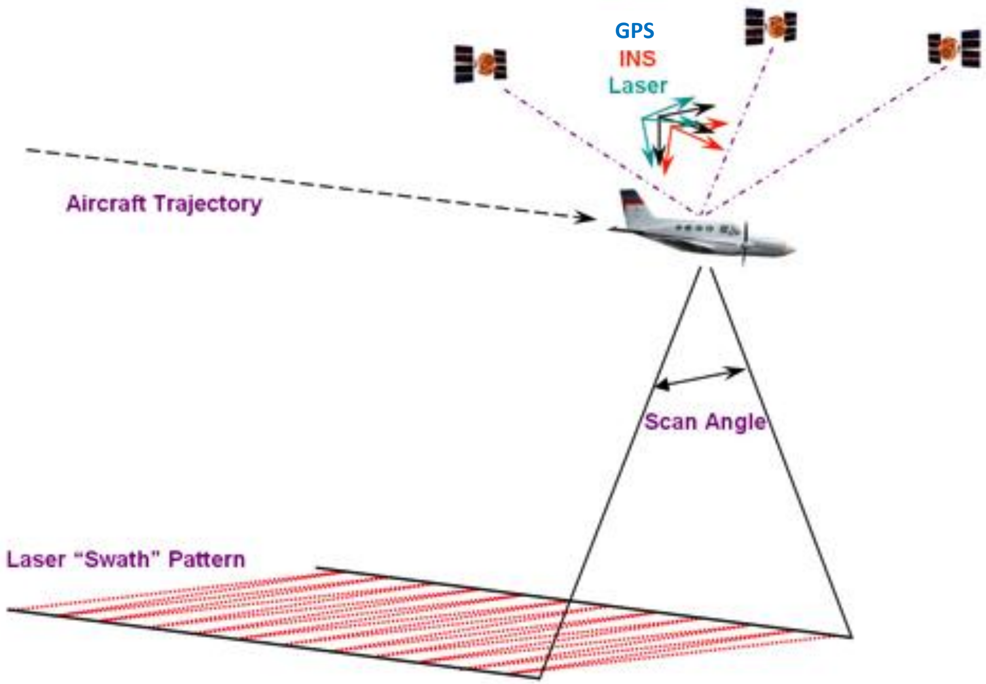
Geodesy and Remote Sensing
Natural Hazards Program

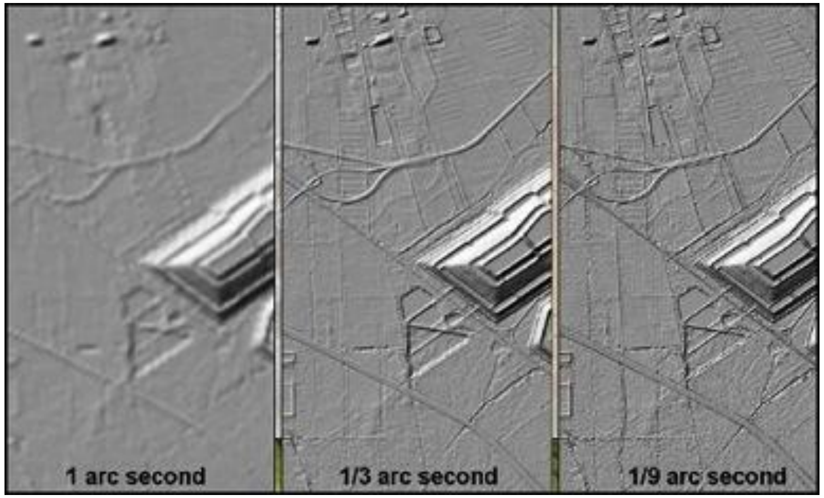
- **Natural hazards program - research in earthquakes, volcanoes, landslides, subsidence, etc.**



- **Technologies**
  - **Global Navigation Satellite Systems (GNSS)**
    - **Global Positioning System (GPS)**
  - **LiDAR – airborne and ground based tripod**
  - **Digital photography – airborne and spaceborne**
  - **Radar - InSAR and PSInSAR**
  - **Gravity – absolute, relative and airborne**
- **Applications**
  - **High-precision LiDAR mapping of the San Andreas Fault**
  - **Monitoring land surface deformation; landslides**
  - **Volcanoes**
  - **Measurements of water level changes**
  - **Subsidence measurements**

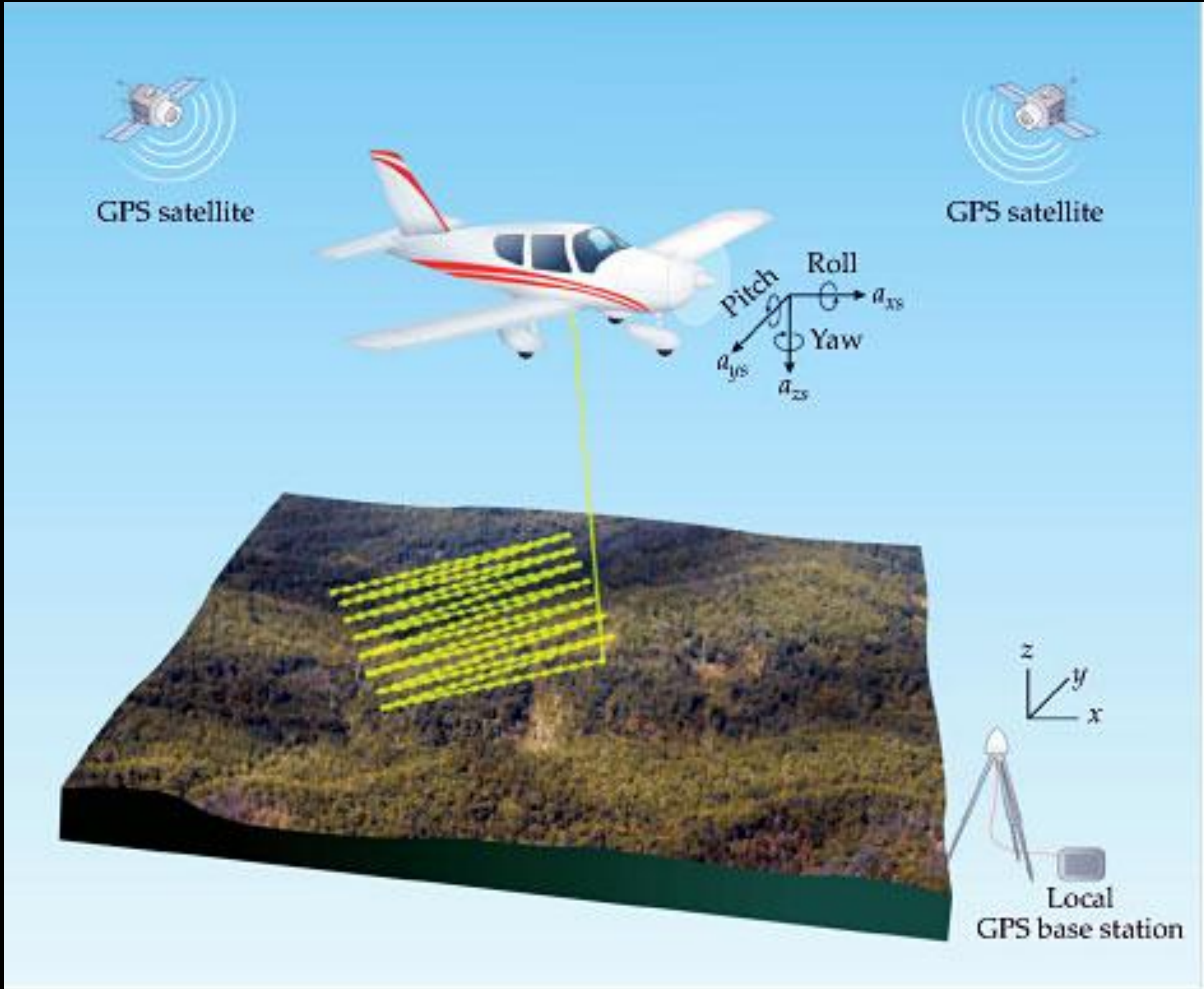
GPS is used to provide precise positions of airborne sensors so that highly accurate base geospatial data products such as high resolution terrain (elevation) data and orthorectified imagery can be produced efficiently.

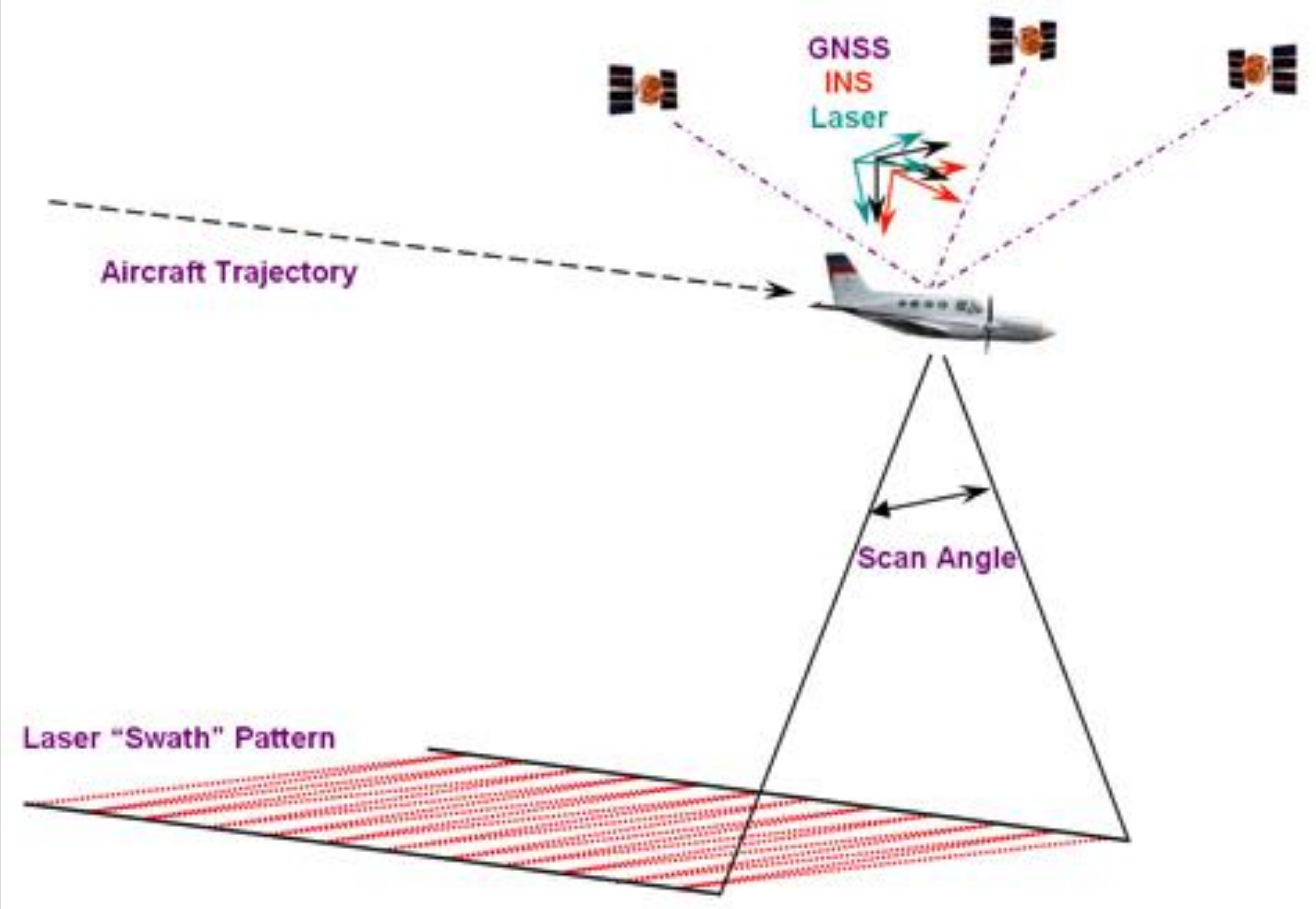




Highly accurate terrain elevation data is replacing older, lower resolution data

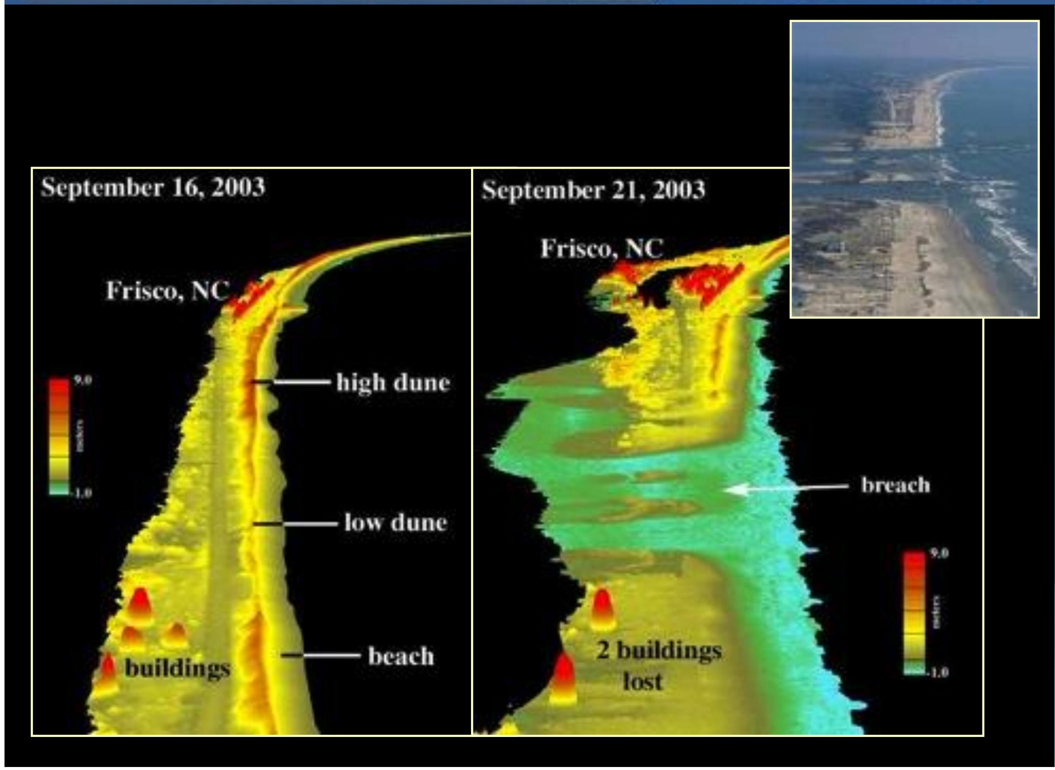
Example of high resolution orthorectified imagery acquired in
Partnership between USGS and other
Fed, state, and local Govt agencies


GPS satellite
GPS satellite
Roll
Pitch
Yaw
a_{xs}
a_{ys}
a_{zs}
z
y
x
Local
GPS base station

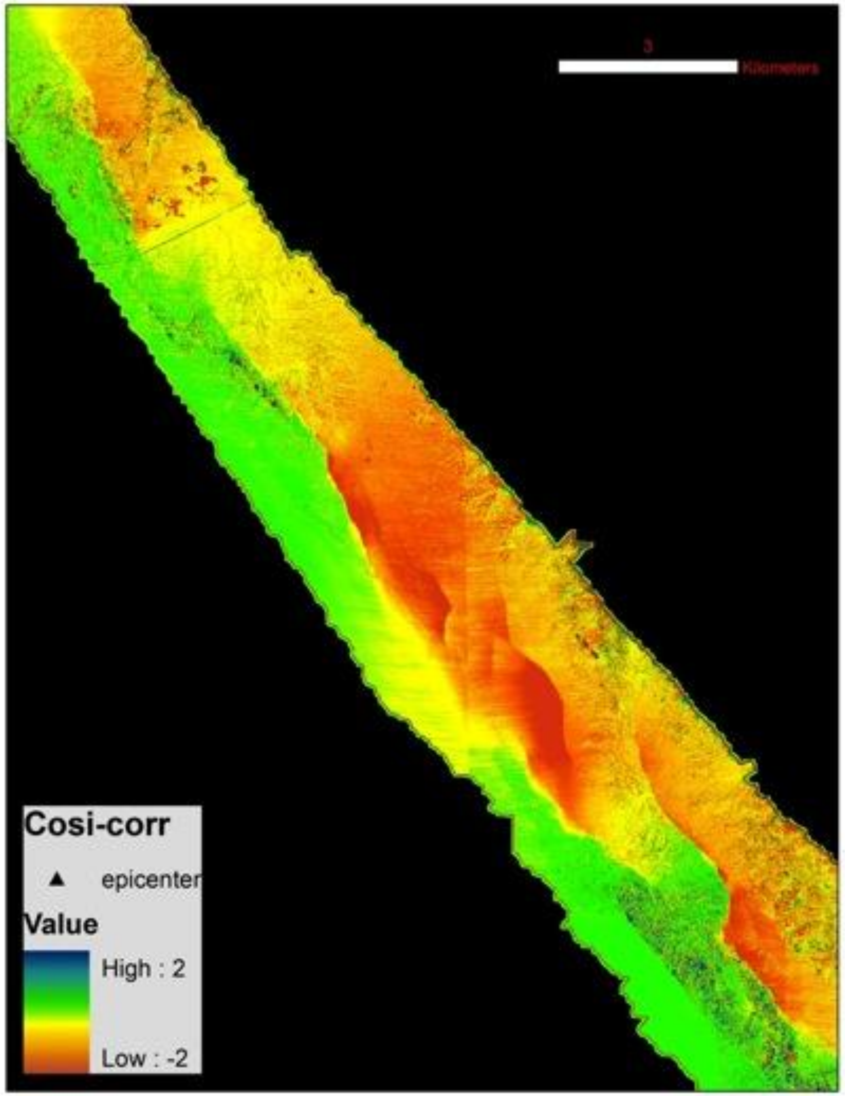

GNSS
INS
Laser
Aircraft Trajectory
Scan Angle
Laser "Swath" Pattern


Coastal Change Hazards


Coastal Response to Hurricane Katrina - Dauphin Island, AL
Gulf of Mexico
N
Mississippi Sound
erosion
accretion
September 2004
difference (2005-2004)
0 - 2m
4 - 6m
10 - 12m
September 2005
September 2005
USGS
(modified after Sallenger et al, 2005)


September 16, 2003
Frisco, NC
high dune
low dune
beach
buildings
September 21, 2003
Frisco, NC
breach
2 buildings lost


GPS Dependent Airborne LiDAR
Mapping Enables Understanding
of Coastal Change Hazards



GPS enables ultra-high-precision geo-ref for fault mapping using repeat-pass imagery

- LiDAR
- 3D stereo

“B4” Project Objectives

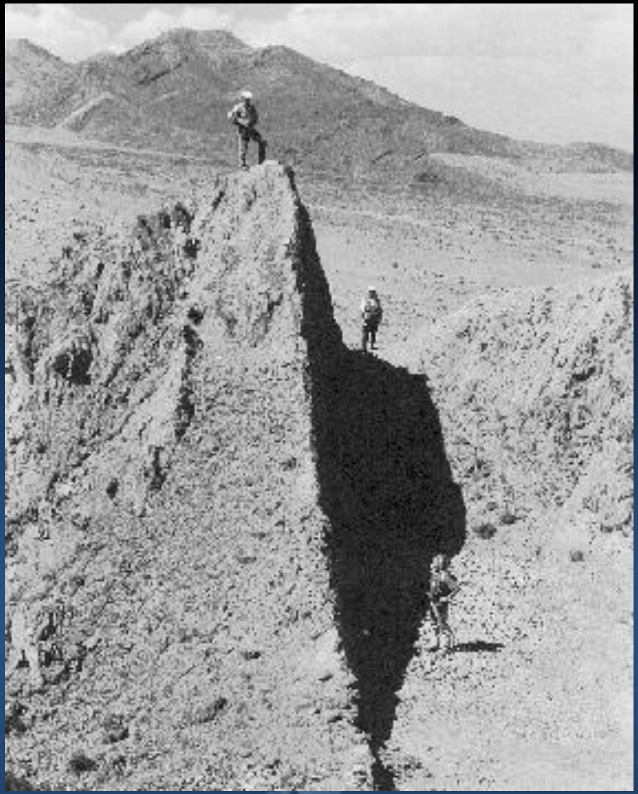
- Aerial survey and map the southern San Andreas Fault, as well as the San Jacinto and Banning faults, using integrated GPS-aided Inertial LIDAR & digital camera systems
- Validate the instrumentation and procedure for applying direct geopositioning data in the navigation-based photogrammetric process
- Assess the potential of these systems for post-event earthquake emergency response

Motivation

- **Densify observations along fault corridor by high accuracy topographic mapping of surface ruptures and active fault scarps**
  - **slip models for prehistoric events**
  - **rapid assessment of surface slip and damage patterns after large events**
  - **source physics experiment to observe slip heterogeneity**

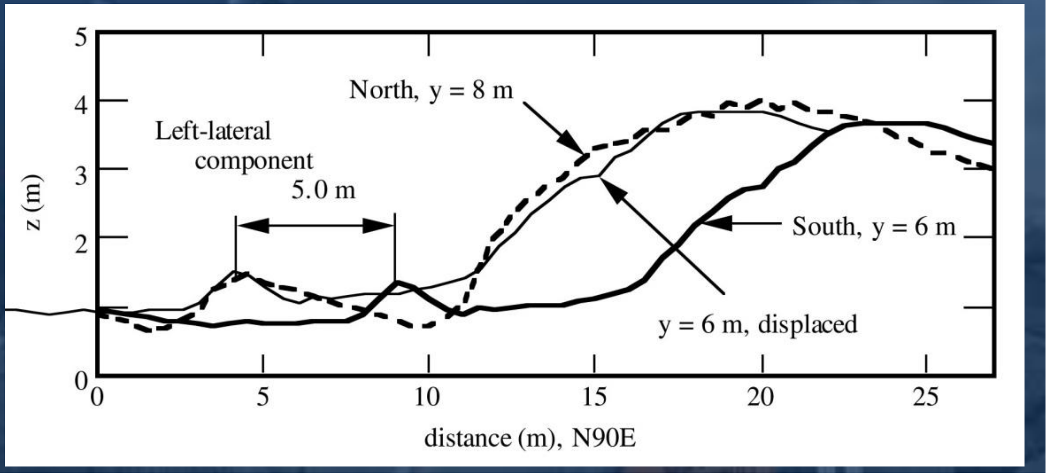
Quantifying Fault Slip and Rupture

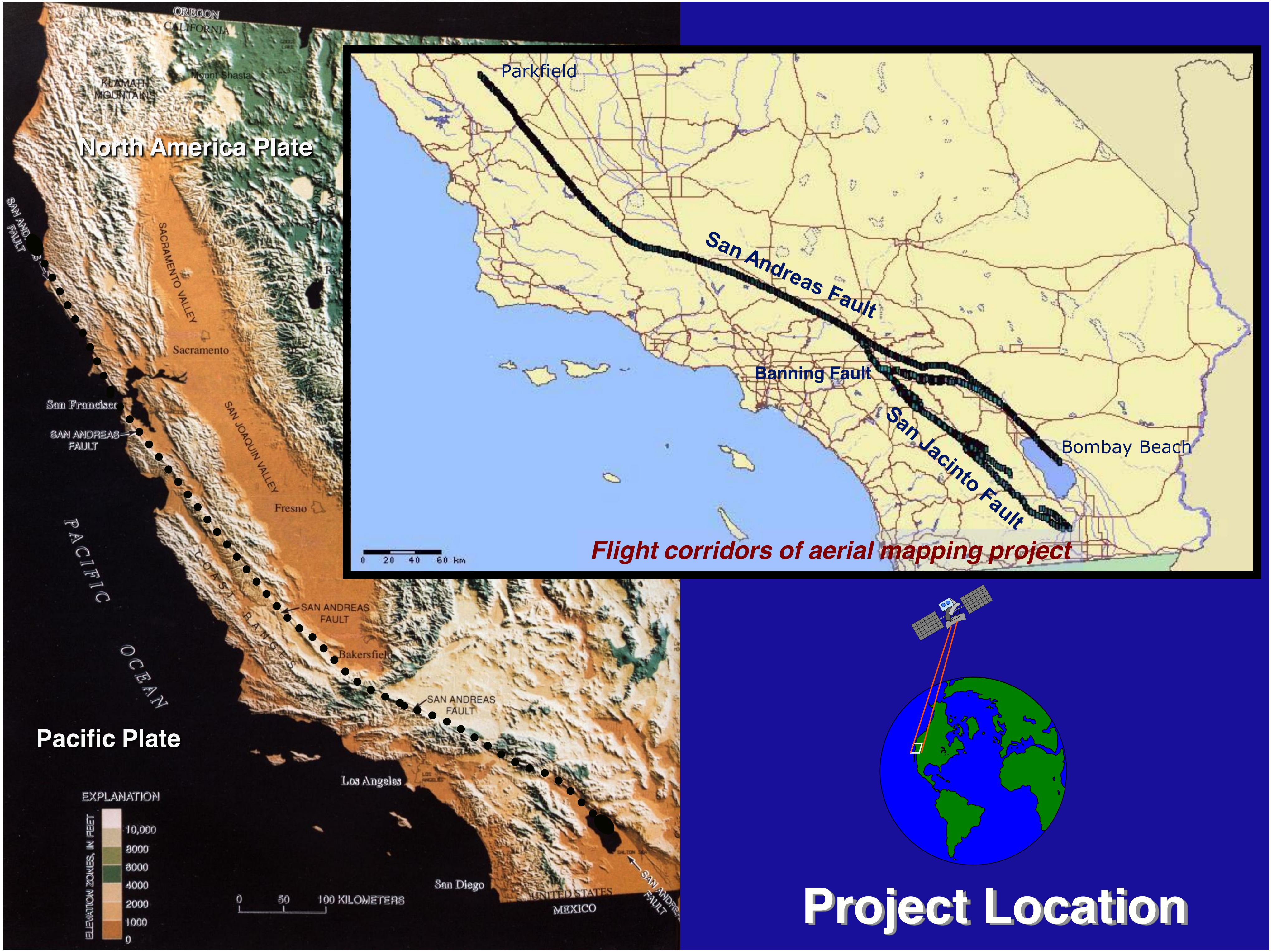
Representation of actual fault ruptures recorded and preserved in unprecedented detail for use by future earthquake researchers



1957 Gobi-Altai earthquake surface rupture

Kurushin et al. (GSA Special Paper, 1997)

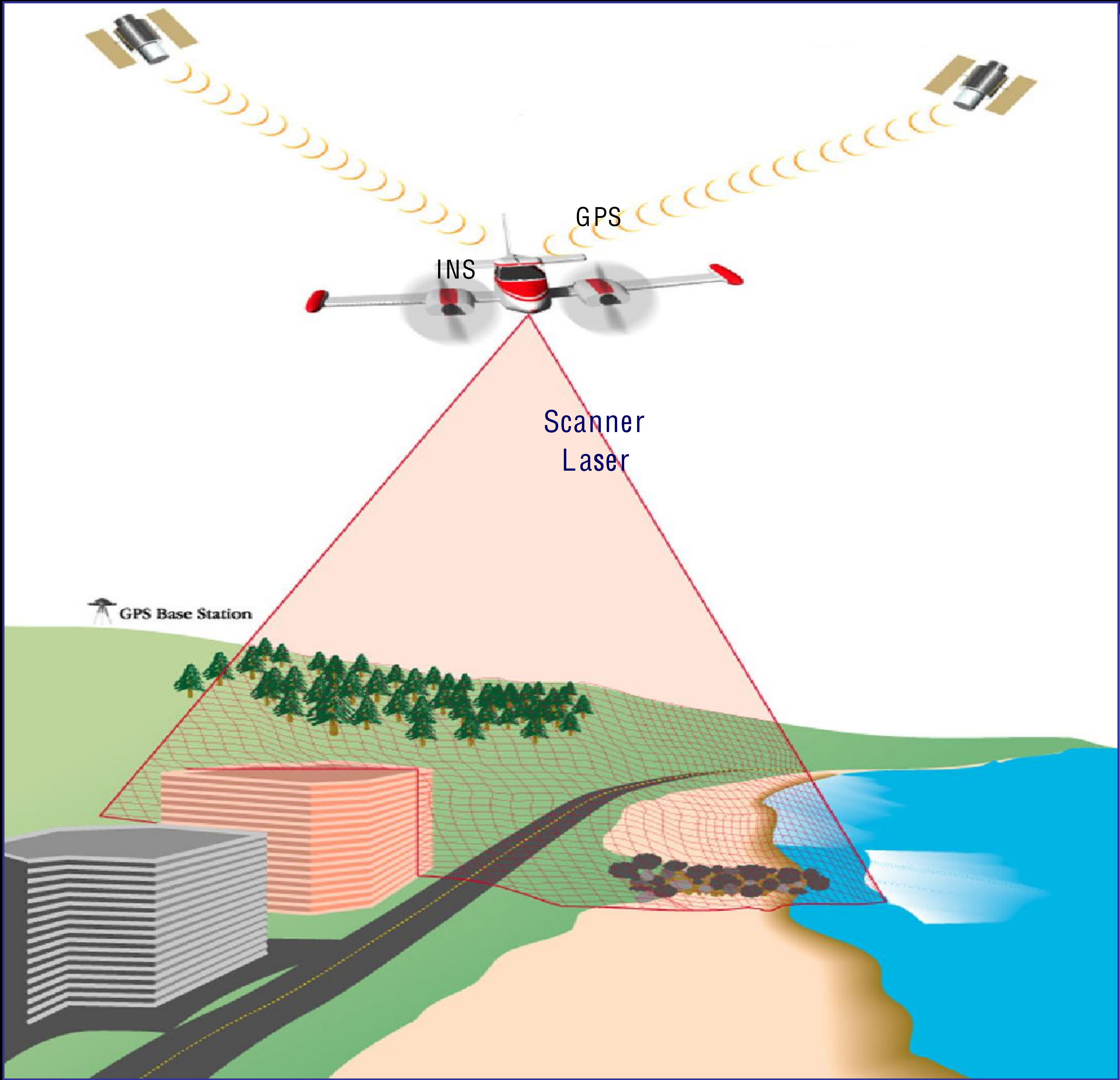




Project Location

NCALM Cessna 337 Skymaster

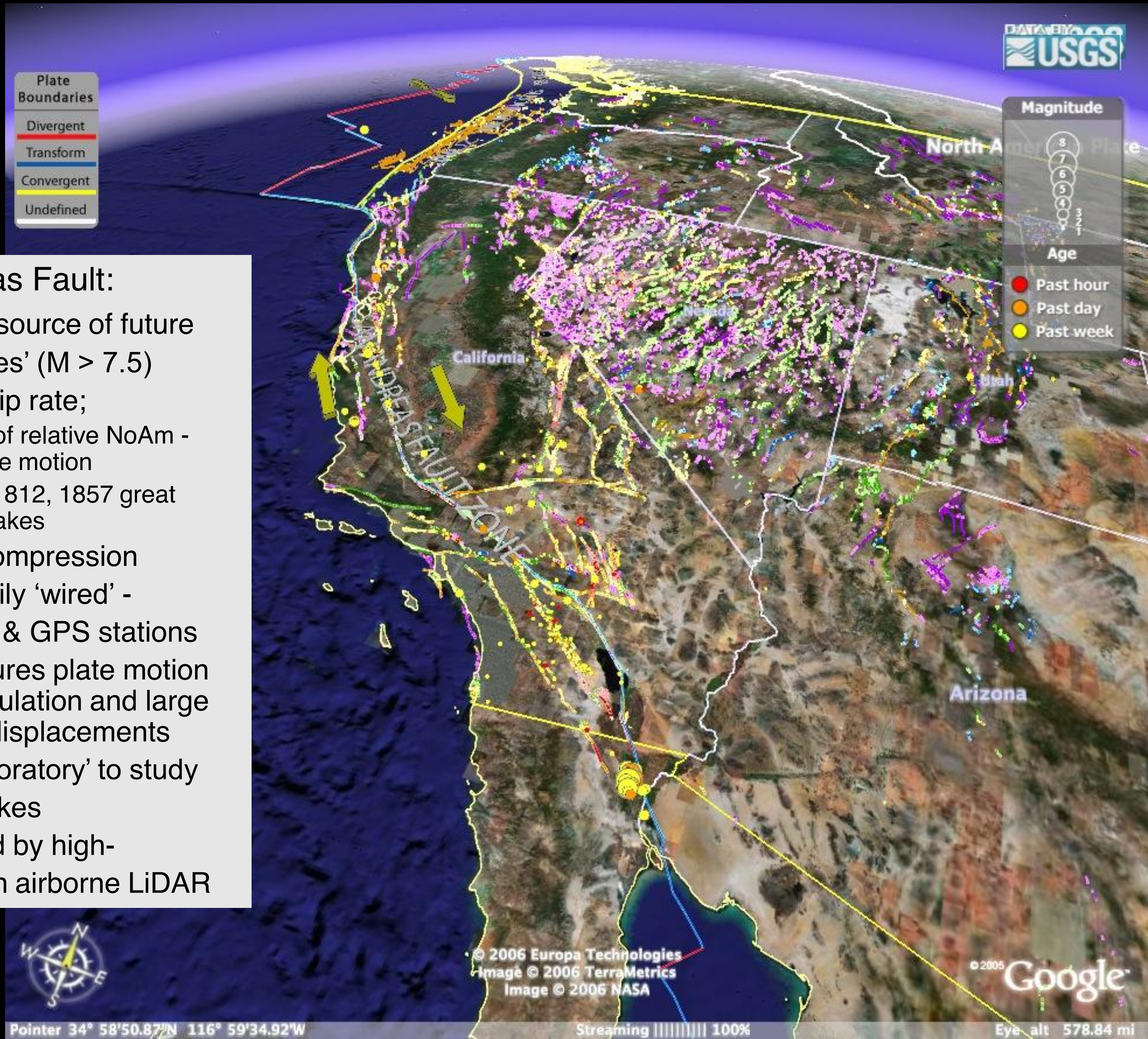
(University of Florida's ALTM 1233)



Airborne LIDAR

San Andreas Fault:

- Most likely source of future 'Big Ones' (M > 7.5)
- 35 mm/yr slip rate;
  - >70% of relative NoAm - Pac plate motion
  - 1680, 1812, 1857 great earthquakes
- Big Bend compression
- SoCal heavily 'wired' - seismic & GPS stations
- GPS measures plate motion strain accumulation and large earthquake displacements
- 'Natural laboratory' to study earthquakes
- B4 - imaged by high-resolution airborne LiDAR



San Andreas Fault - Research

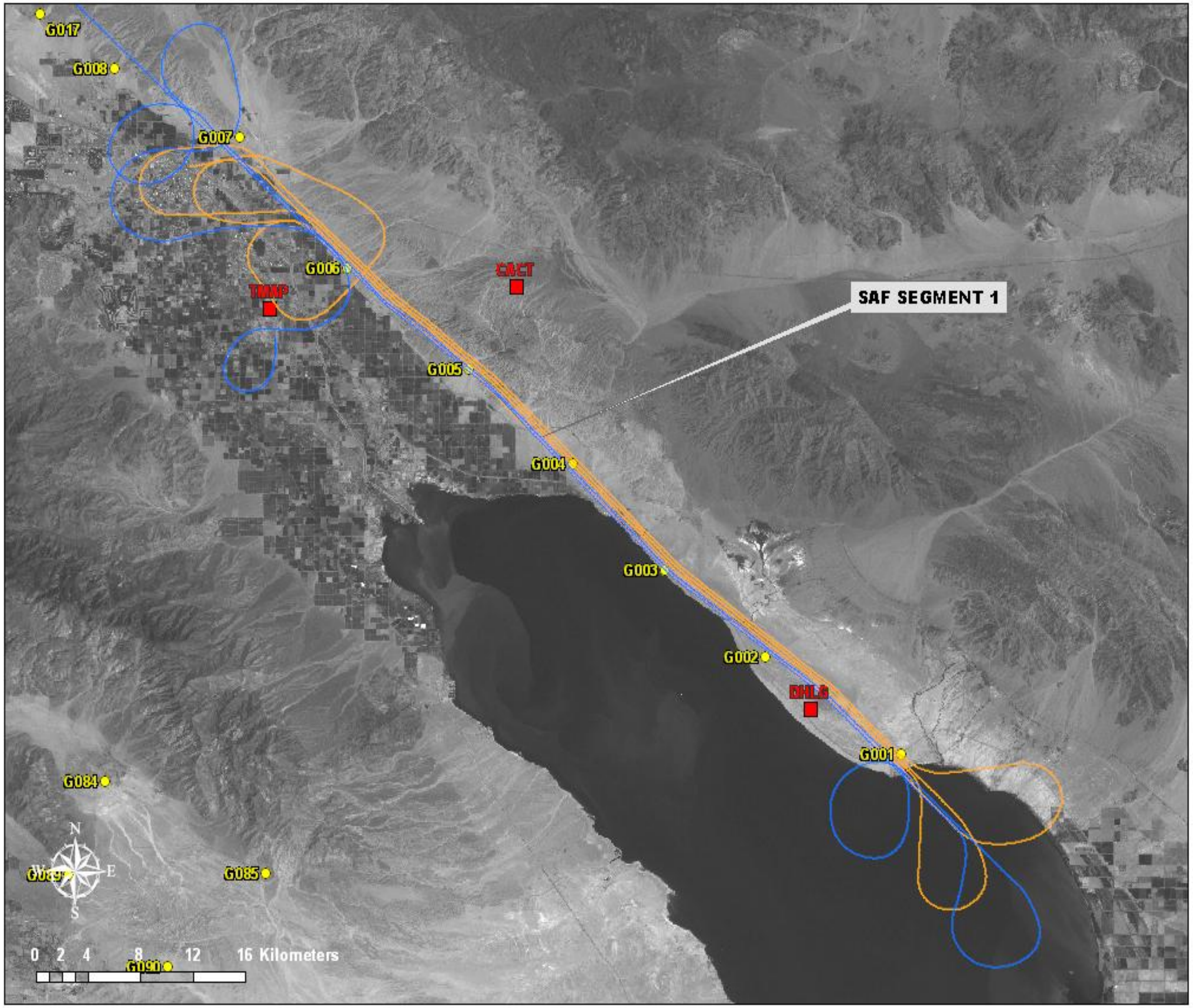
B4 - pre-earthquake high-resolution LiDAR; an earthquake source physics experiment (funded by NSF, joint w/ USGS) to image slip variation as a proxy for stress heterogeneity

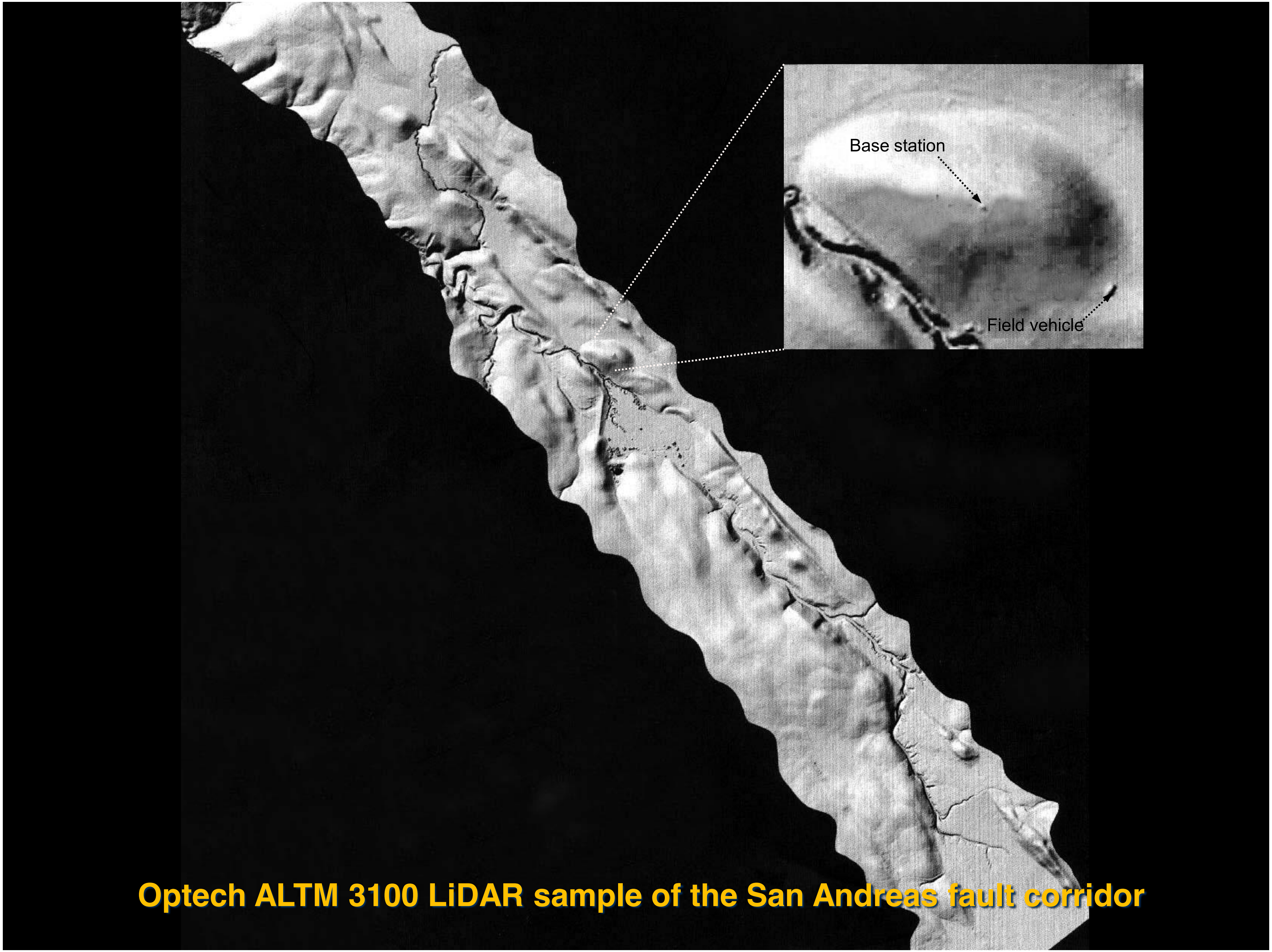
SoSAFE - Southern San Andreas Fault Evaluation (SoSAFE) Project of the Southern California Earthquake Center (SCEC); research to obtain improved data on timing and slip in past earthquakes and fault slip rates (funded by USGS, joint w/ NSF)

Flight corridor #11 with location of base stations & ground control points

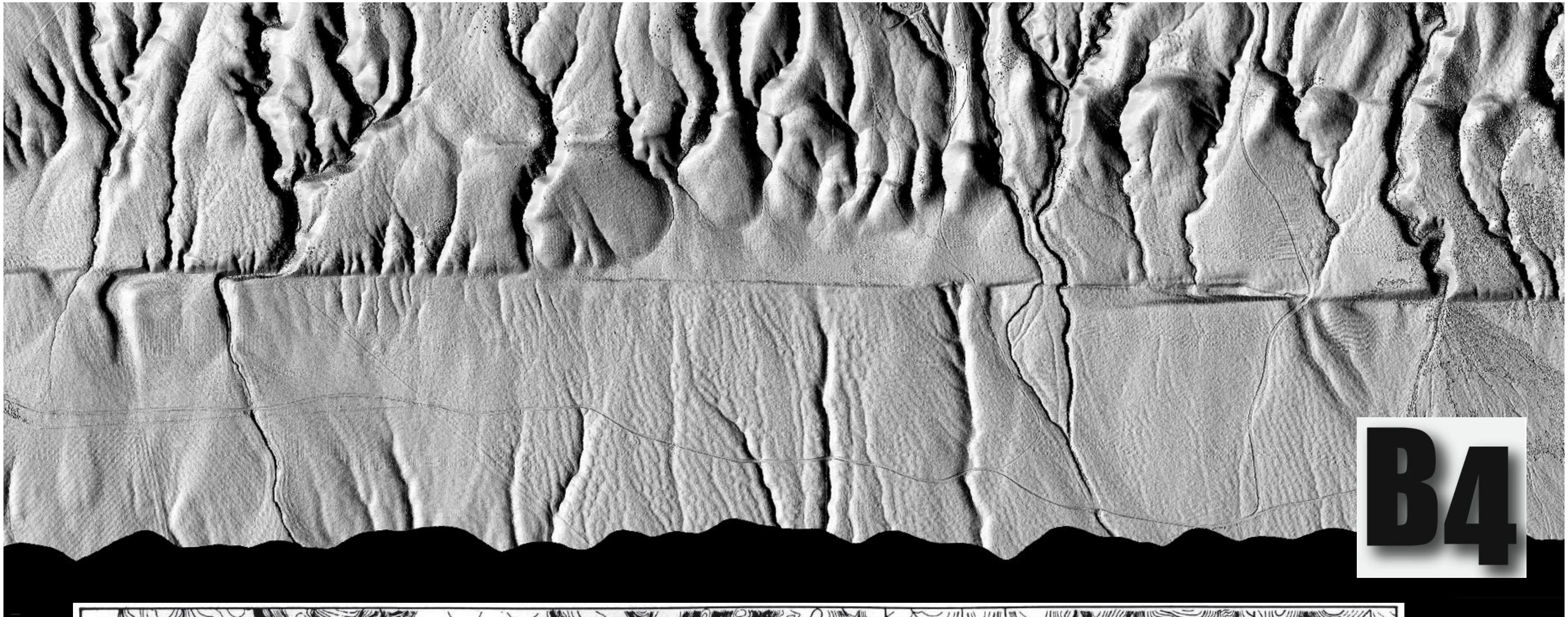
In this aerial photo illustration the yellow line represents the general direction of the fault, the red dots are flight mission waypoints, the **white triangles** are the GPS reference base stations, and the yellow circles are supplemental GPS ground control points

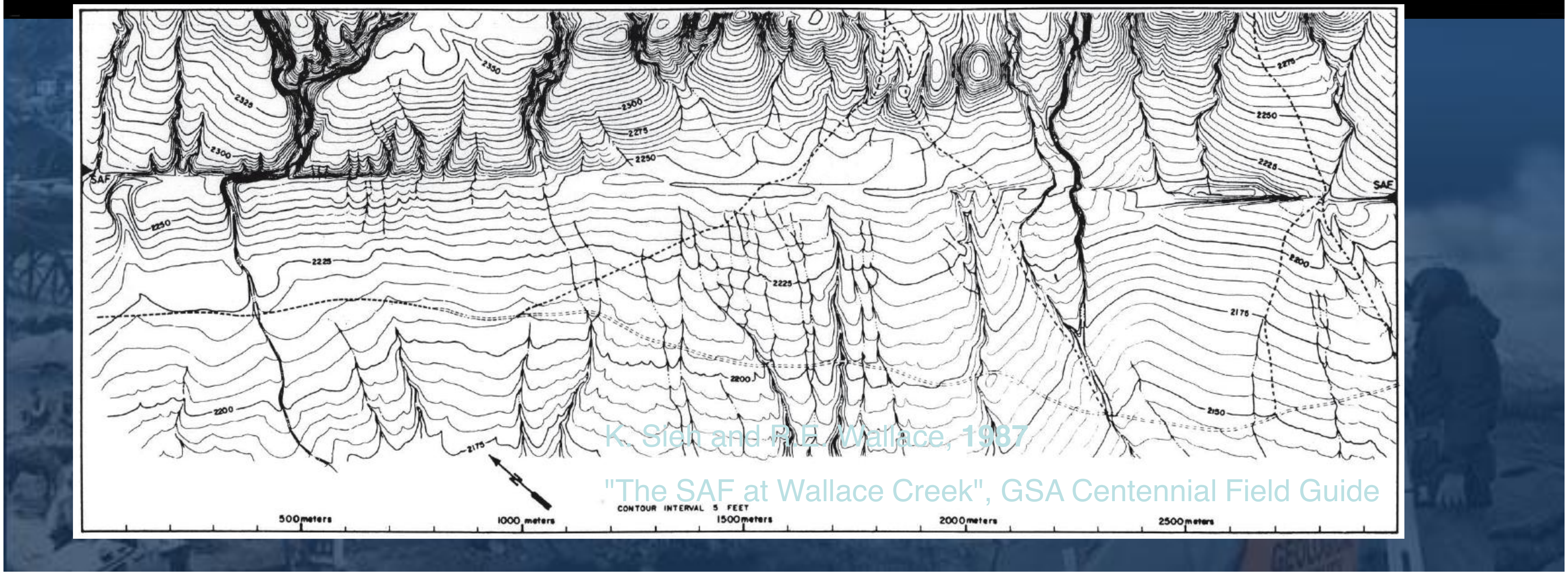
Five passes along each 50 km segment; data then merged





Optech ALTM 3100 LiDAR sample of the San Andreas fault corridor

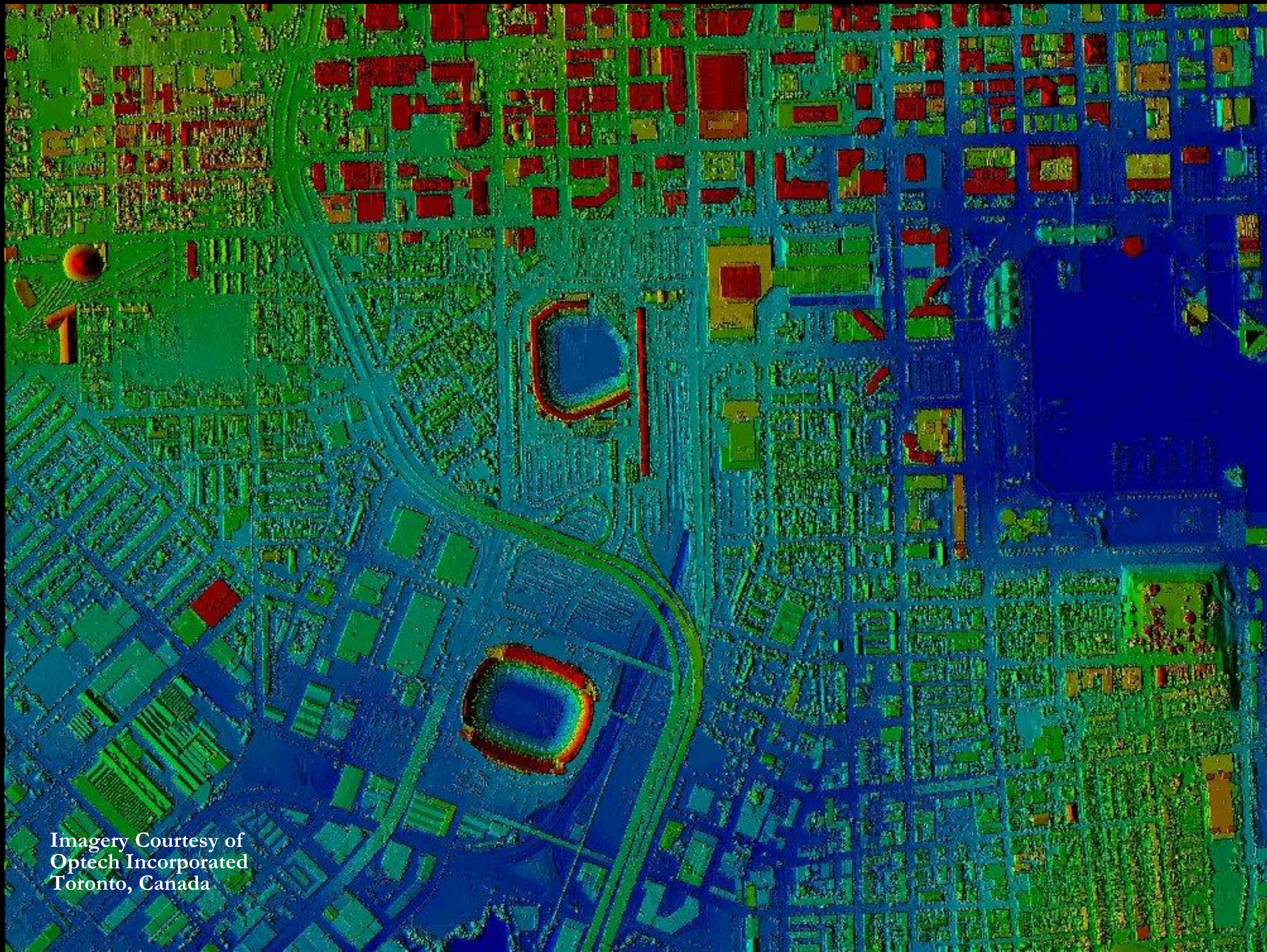




K. Sieh and R.E. Wallace, 1987

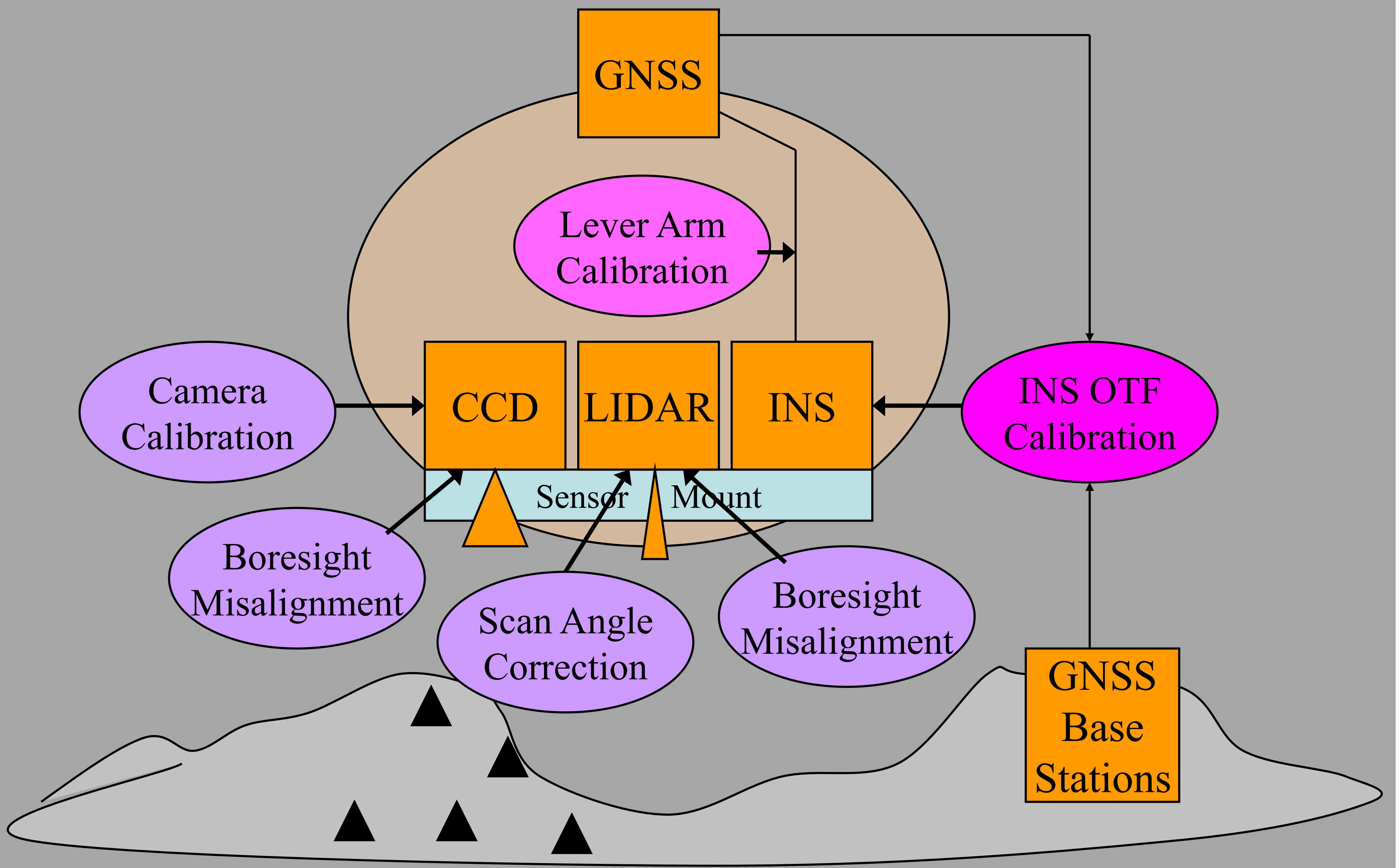
"The SAF at Wallace Creek", GSA Centennial Field Guide

LIDAR determined heights



LIDAR Intensity

LIDAR/Camera System Calibration



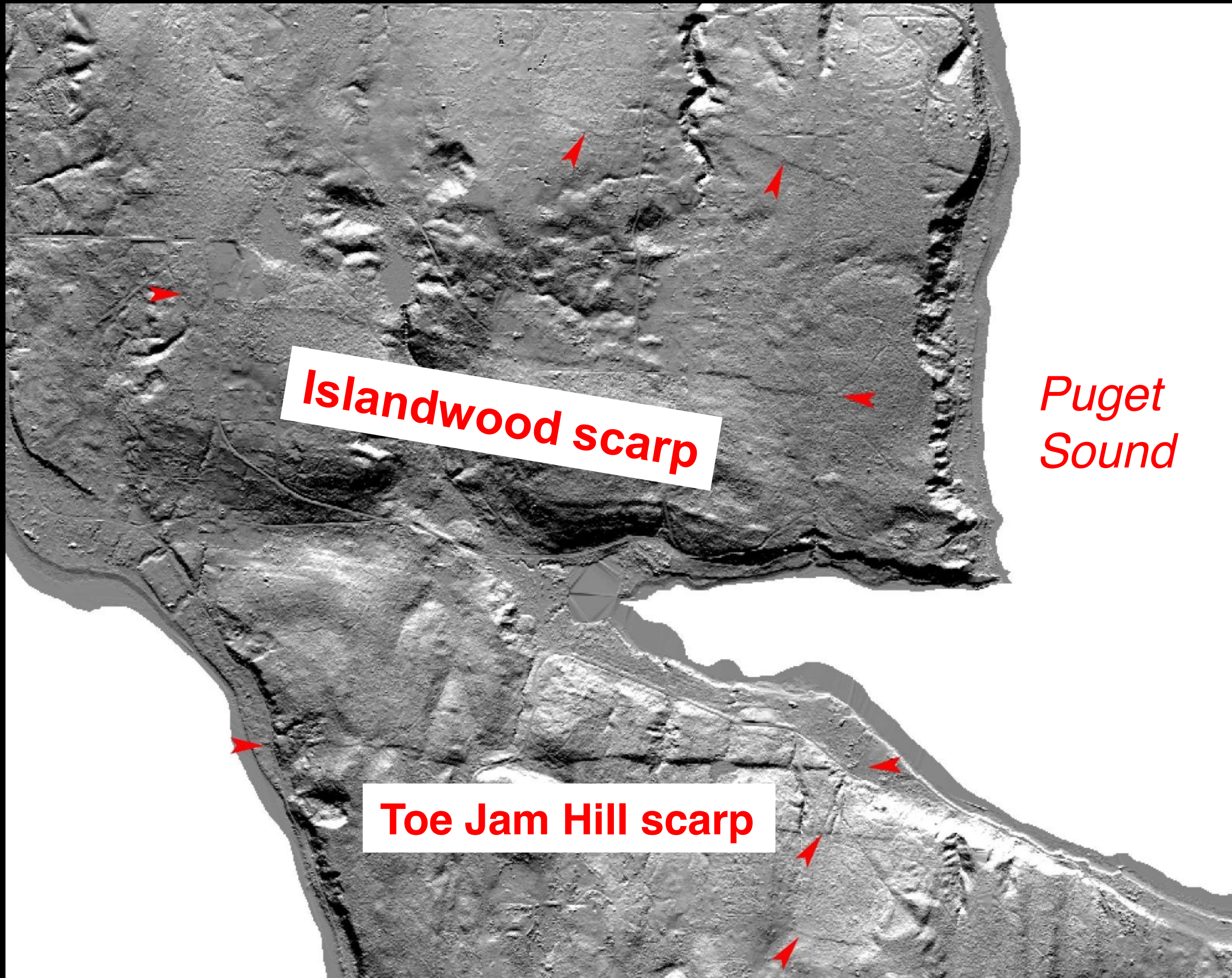
Performance of LIDAR

The accuracy of LIDAR depends on:

- System parameters: outgoing pulse shape, signal level
- Measurement uncertainties including background solar radiation, thermal noise, speckle noise
- Target signatures (geometry and reflectivity)
- Environmental conditions, e.g. atmospheric delay, cloudiness
- Estimation method used for range measurement
- Accuracy for determining trajectory and attitude of the sensor platform - aircraft

LIDAR: Revolutionizing hazard mapping in the Pacific Northwest and elsewhere

Bainbridge Island, Washington

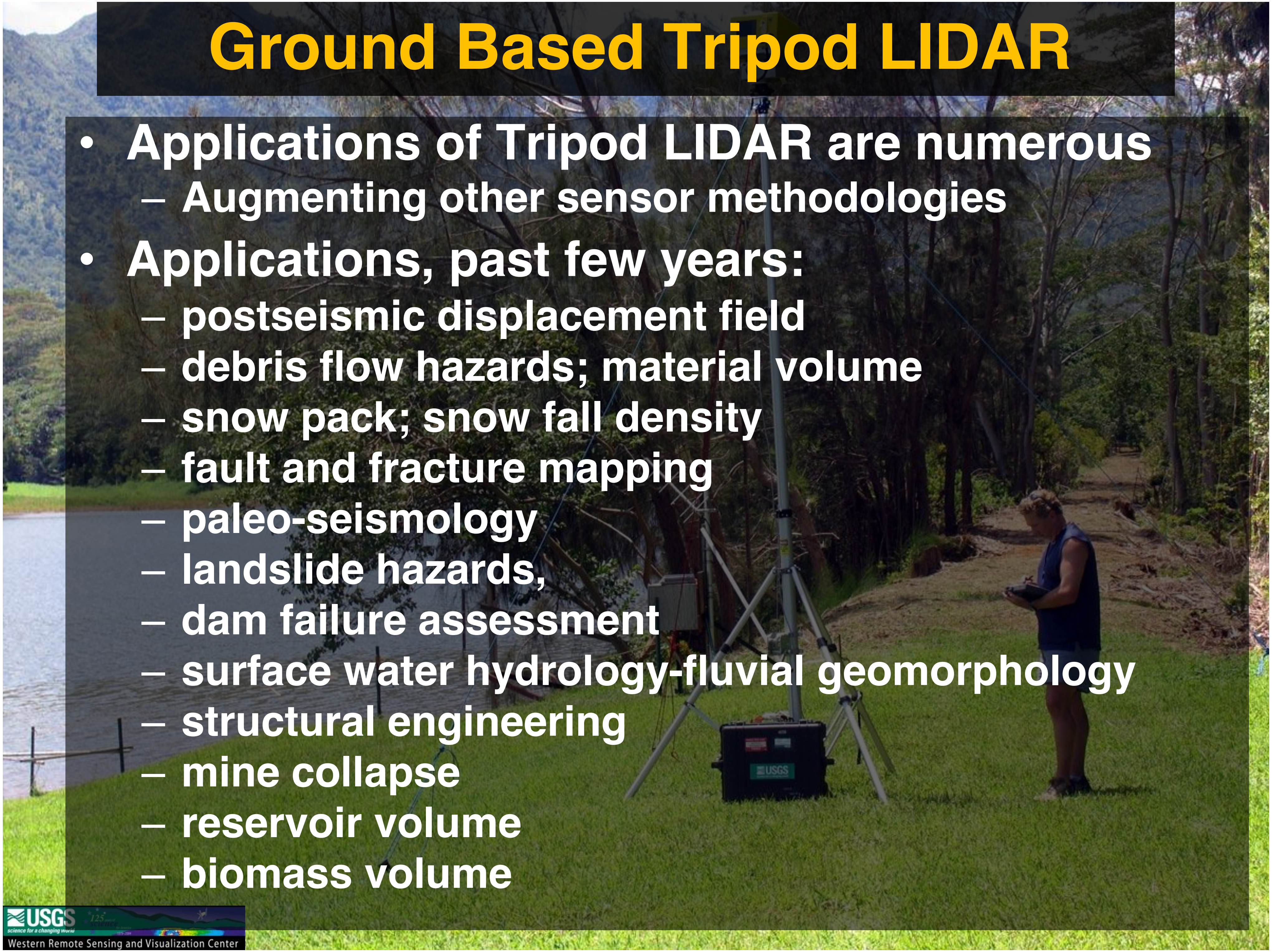


Ground Based Tripod LIDAR

Gerald Bawden, Jim Howle & Sandra Bond
US Geological Survey - Sacramento, California
Randal Osterhuber – Univ. of California Berkeley

USGS
science for a changing world
Western Remote Sensing and Visualization Center

Ground Based Tripod LIDAR

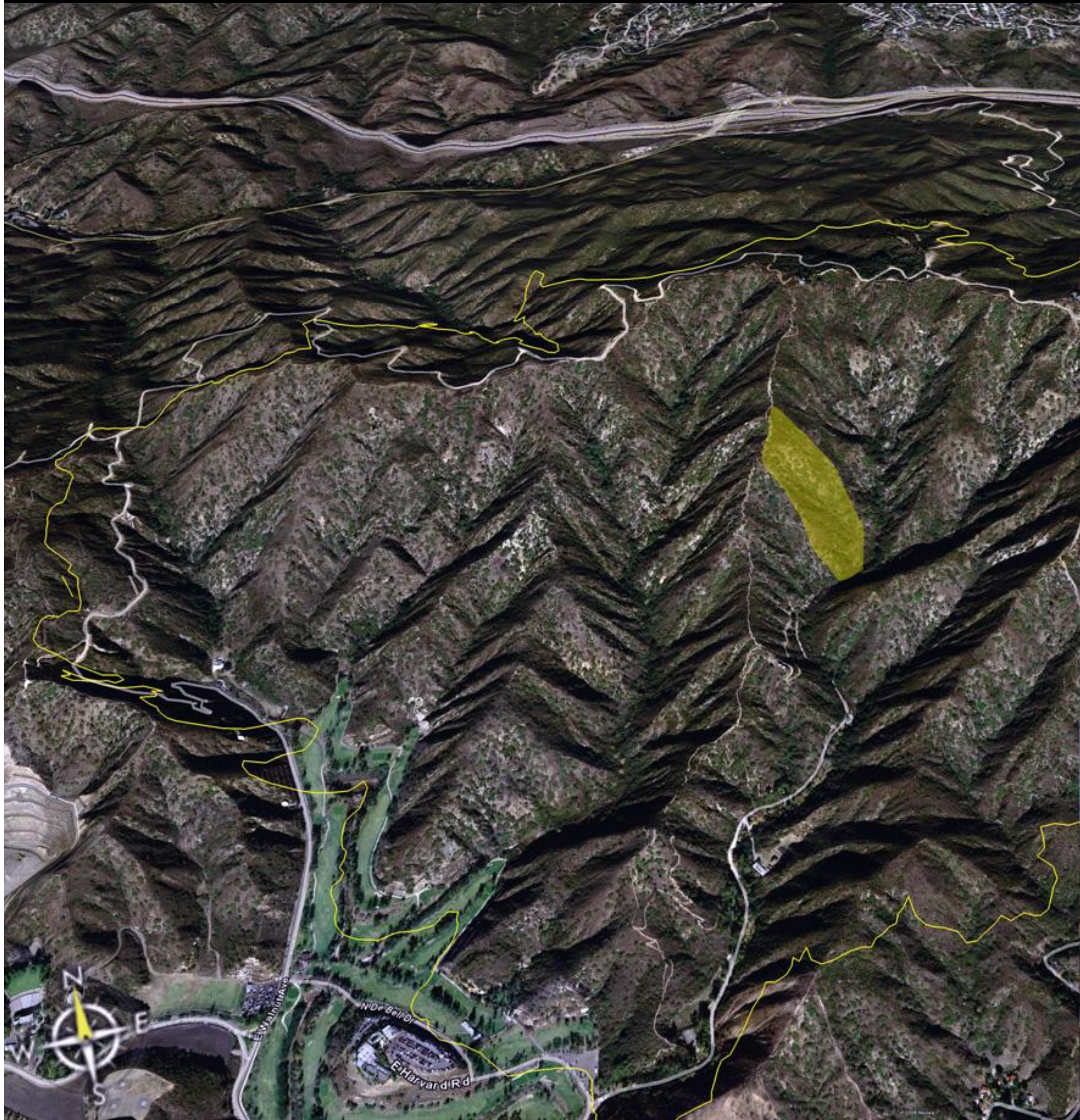


- Applications of Tripod LIDAR are numerous
  - Augmenting other sensor methodologies
- Applications, past few years:
  - postseismic displacement field
  - debris flow hazards; material volume
  - snow pack; snow fall density
  - fault and fracture mapping
  - paleo-seismology
  - landslide hazards,
  - dam failure assessment
  - surface water hydrology-fluvial geomorphology
  - structural engineering
  - mine collapse
  - reservoir volume
  - biomass volume

Ground Based Tripod LiDAR

- **Applications - unlimited**
  - glacier science
  - levee stability
  - Avalanche
  - land surface processes
  - beach erosion
  - sand dune migration
  - crop health
  - land subsidence
  - coseismic offsets
  - fault and fracture mapping
  - geologic mapping
  - endangered species mapping
  - low tide bathymetry
  - surface water elevation
  - flood measurements
  - ice flow measurements

Harvard Fire -- Burbank, CA



USGS science for a changing world
Western Remote Sensing and Visualization Center

No vegetation + steep terrain + 7.6 cm rain =

Rapid erosion

InSAR and Applications

Zhong Lu
US Geological Survey

Radar - Radio Detection and Ranging

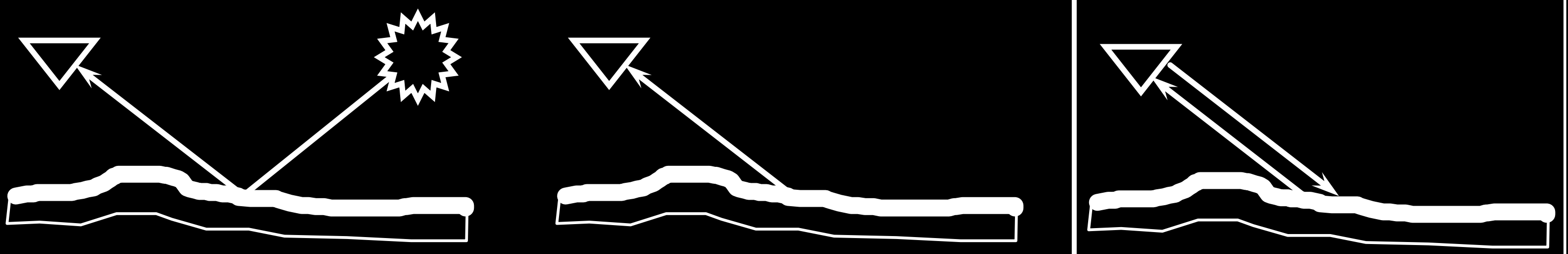
- In its simplest form, a radar operates by broadcasting a pulse of electromagnetic energy into space – if that pulse encounters an object, then some of that energy is redirected or reflected back to the radar antenna and sensor recording instrument.
- Precise timing of the echo delays allows determination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

Synthetic Aperture Radar (SAR)

- An advanced radar system that utilizes image processing techniques to synthesize large antenna to achieve higher spatial resolution.

Remote Sensing: Optical vs. Radar

Sensor	Optical Sensor System		Radar System
Wavelength Region	Visible	Thermal infrared	Microwave



Source	Sun	Object	Transmitted by a sensor system
Object	Reflectance	Thermal radiation (temperature, emissivity)	Backscattering coefficient
Electro-magnetic Spectrum	Visible	Thermal infrared	Microwave

0.4 μm   0.7 μm   3.0 μm   10 μm   1 mm   1 m

Remote Sensing: Optical vs. Radar

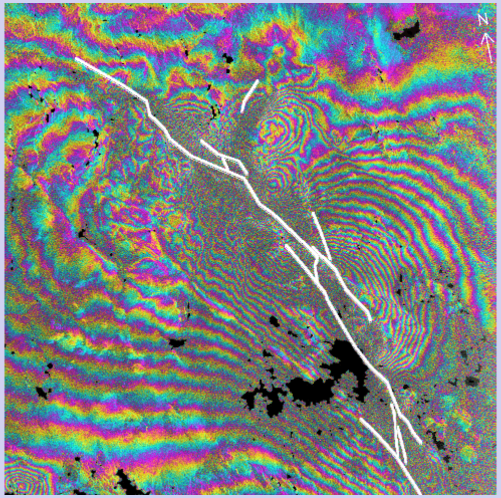
Optical

- passive sensor
- reflectance
- day time acquisition
- cloud problem
- usually nadir
- measure chemical composition and thermal properties

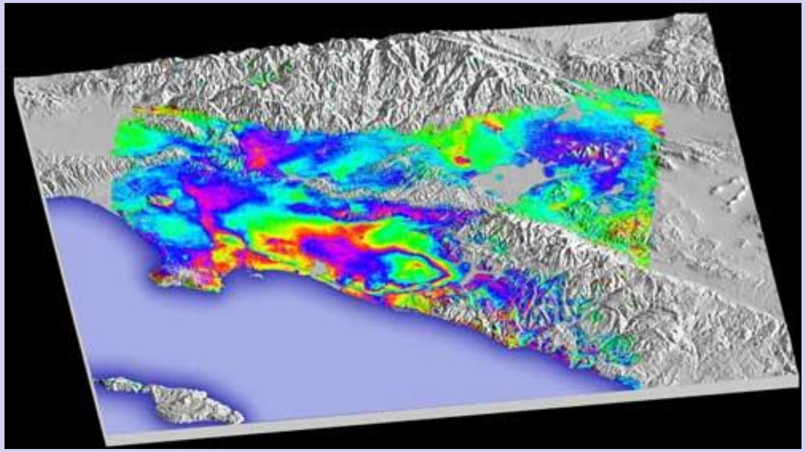
Radar

- active sensor
- backscatter
- day and night
- all weather
- side looking geometry
- measure target physical properties (roughness & dielectric constant)

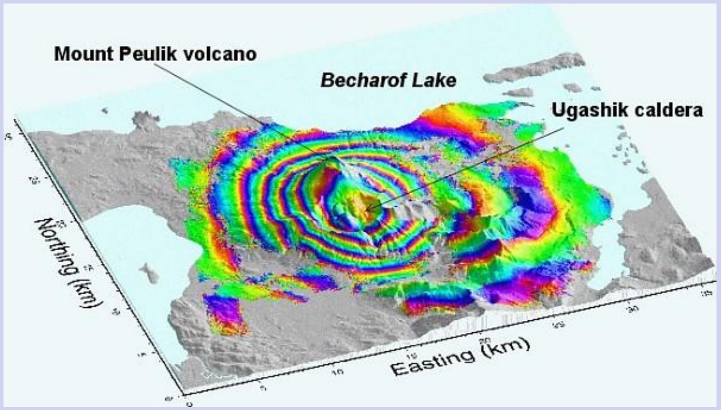
InSAR Applications



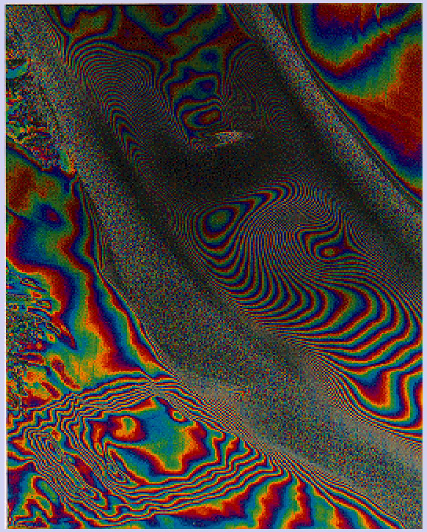
Earthquake deformation

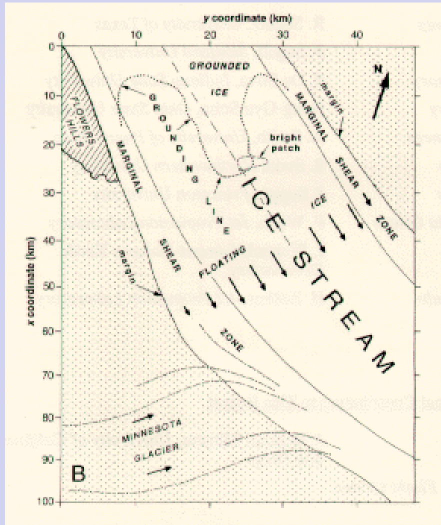


Land subsidence



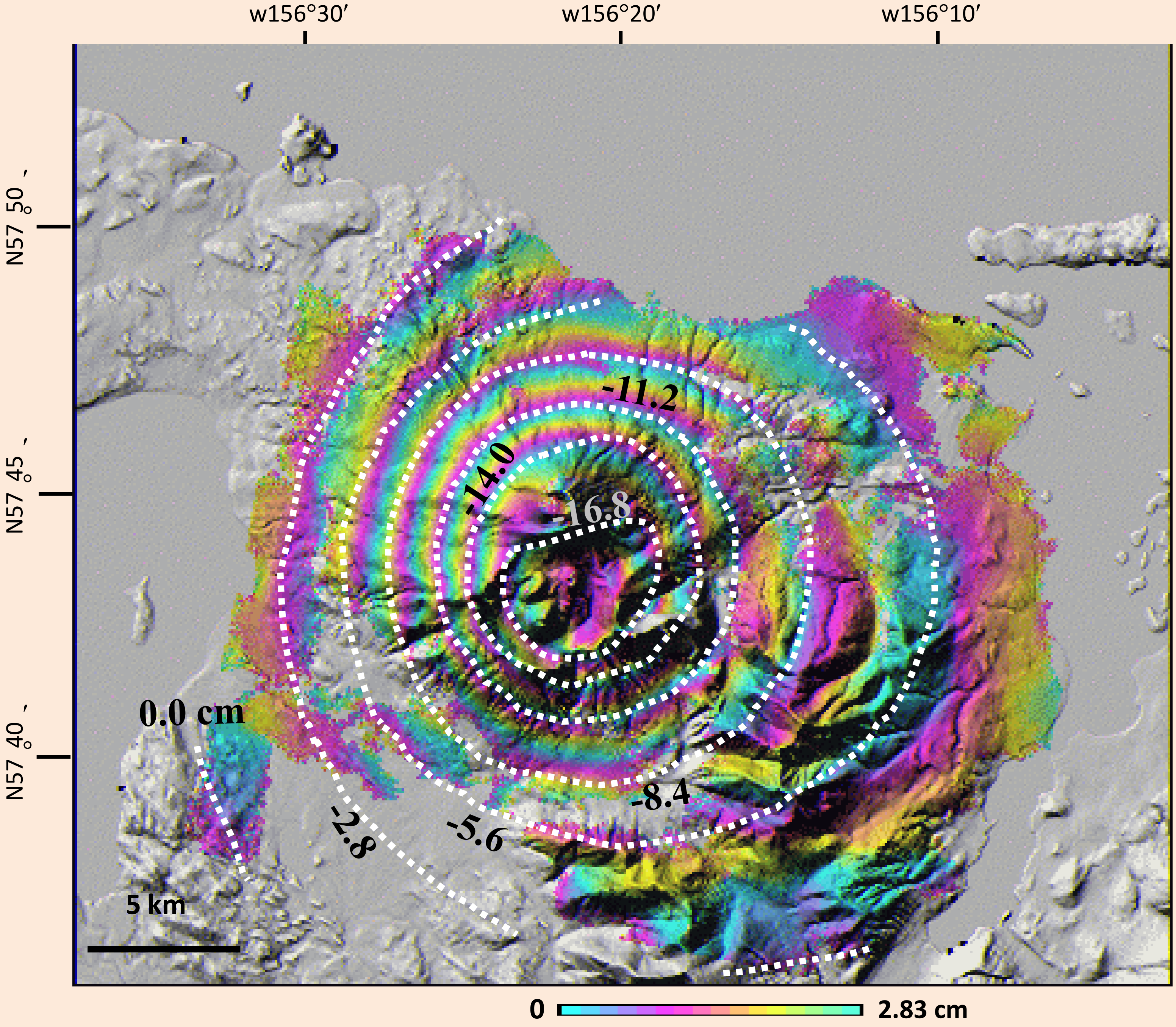
Volcano inflation



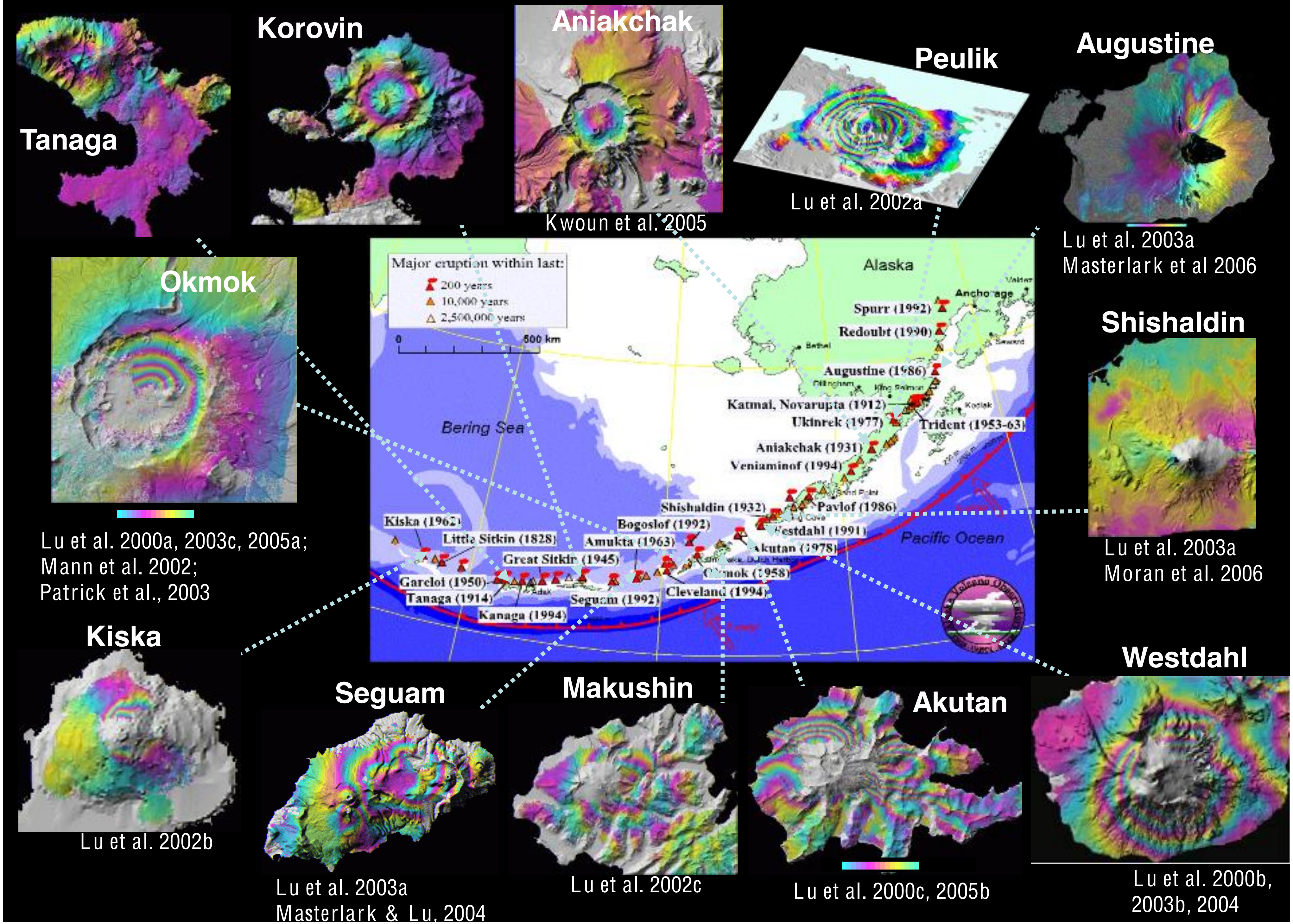


Glacial movement

Deformation interpretation

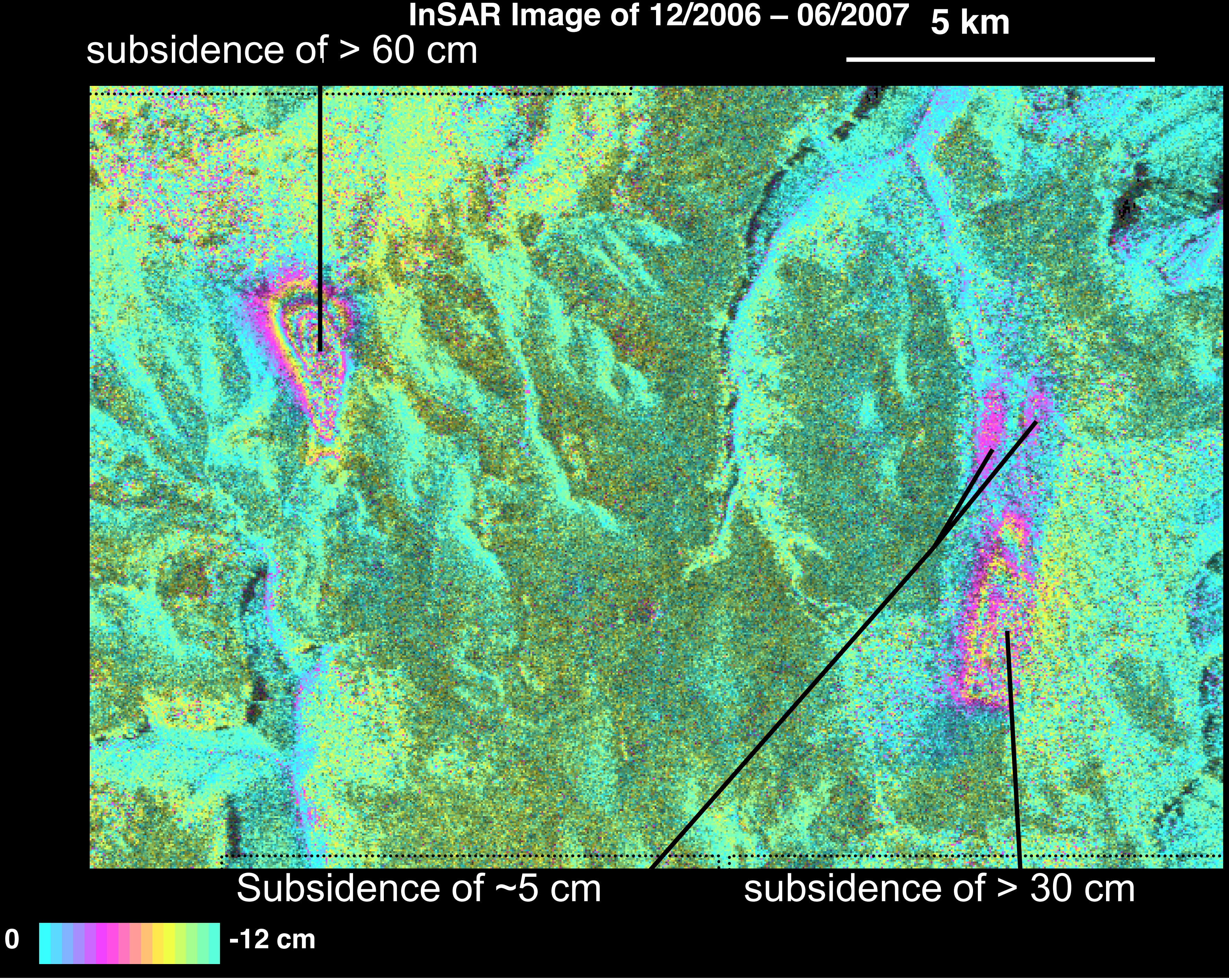


Deformation of Aleutian Volcanoes from InSAR

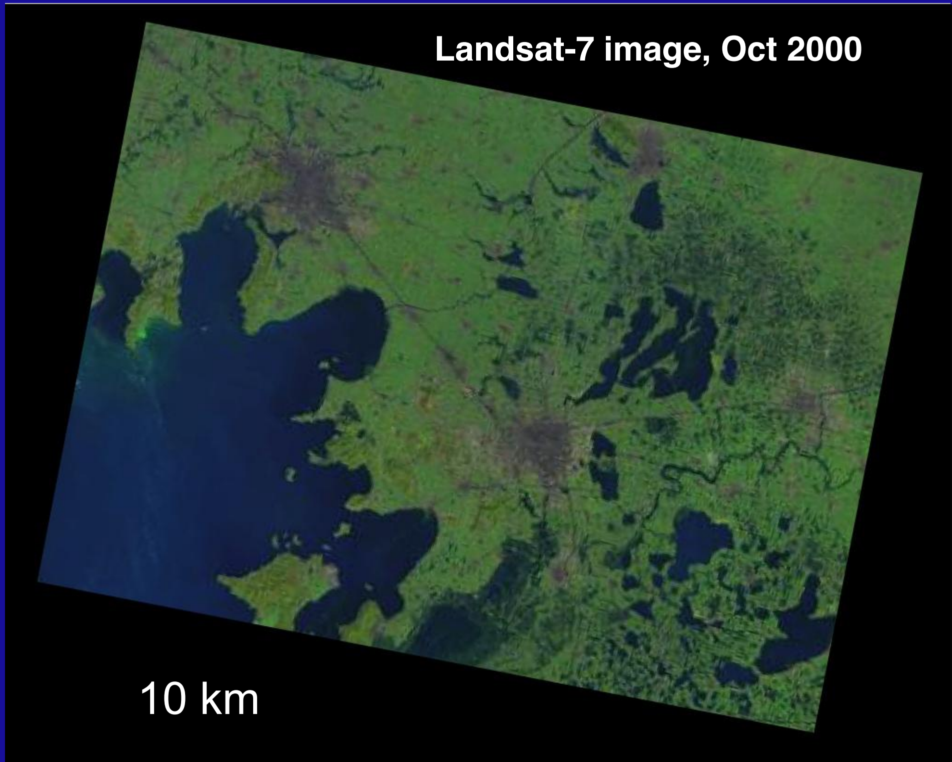


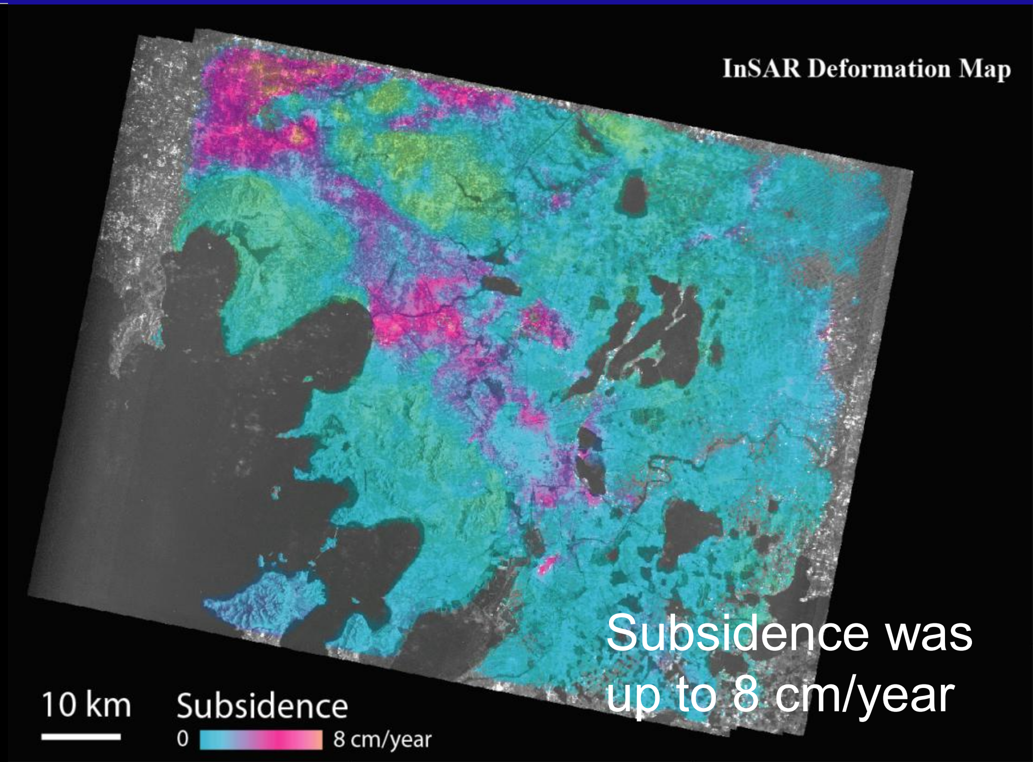
Subsidence in area of underground mines, Utah

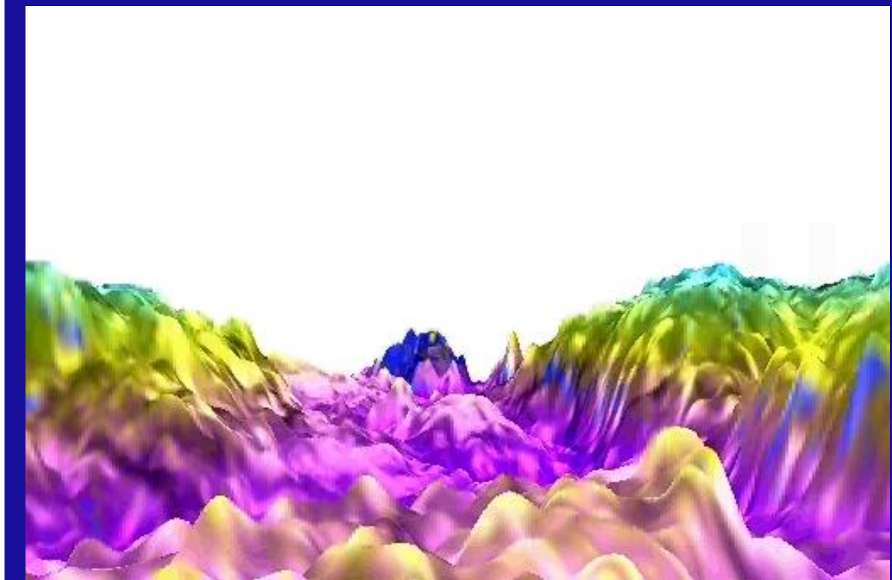
InSAR Image of 12/2006 – 06/2007

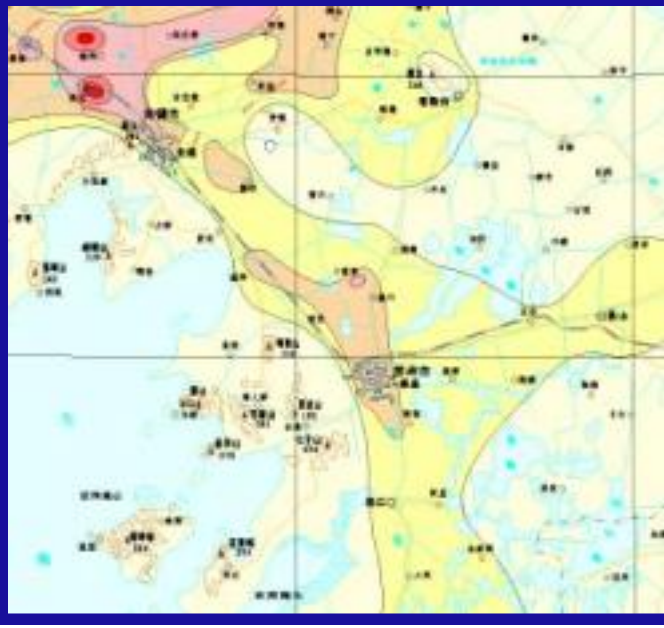


Land Subsidence mapping over coastal China









Geological survey

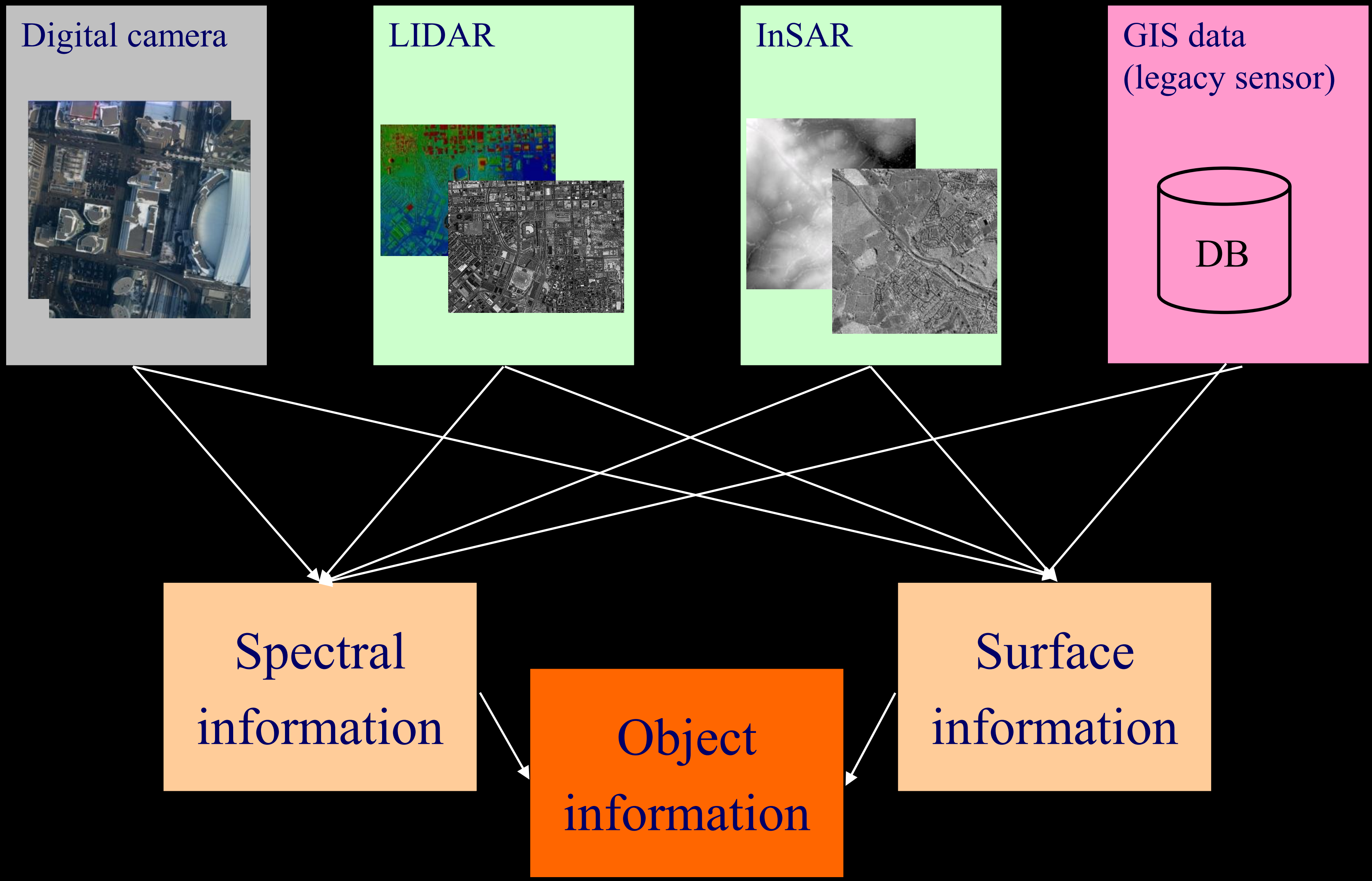
Lu, in prep

Sensor and Image Fusion: Motivation

Growing requirements for surface data

- LiDAR: airborne and terrestrial
- IfSAR
- Digital camera imagery: satellite and airborne
- Sensor integration (GNSS/IMU/Camera/LiDAR)
- Large investment underway in automated surface extraction techniques
- Increasing requirements for near real-time data

Image/Surface Fusion



Summary (1)

Tools or techniques for high-accuracy geodetic observations and measurements

- **GNSS**
  - GPS, GLONASS, GALILEO, COMPASS, QZSS, etc.

- **Remote Sensing**
  - **LiDAR** – airborne and spaceborne
    - Ground based tripod LIDAR
  - **Radar** – InSAR and PSInSAR
  - **Photography**, high resolution and multispectral – ground based, airborne, and spaceborne
  - **Gravity** – absolute and relative – ground, airborne and spaceborne

Summary (2)

Successful use of geodetic measurement tools requires appropriate access to and use of GNSS

- **Geodetic infrastructure - linked to the International Terrestrial Reference Frame (ITRF) at the centimeter-level. Critically important for:**
  - **Regional and global consistency**
  - **Long-term monitoring for change**

- **Use of GNSS is simplified by having access to data acquired at Continuous Operating Reference Stations (CORS)**
  - **Efficient use is dependent on application of international adopted standards for data formats, such as RINEX for GNSS**

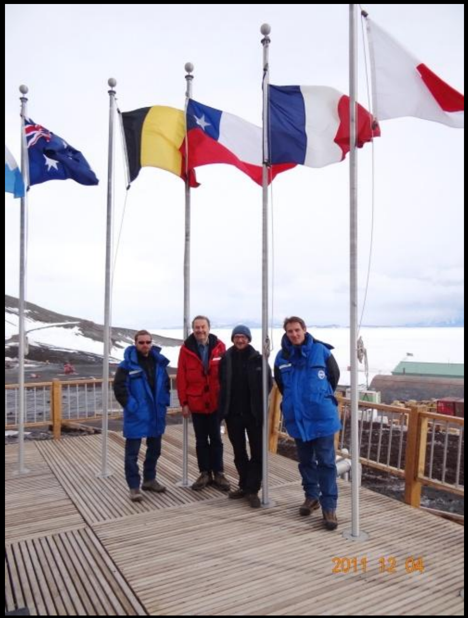

Thank you

Measuring Changes in Height

Geometric with GNSS vs. Absolute Gravity

Case example

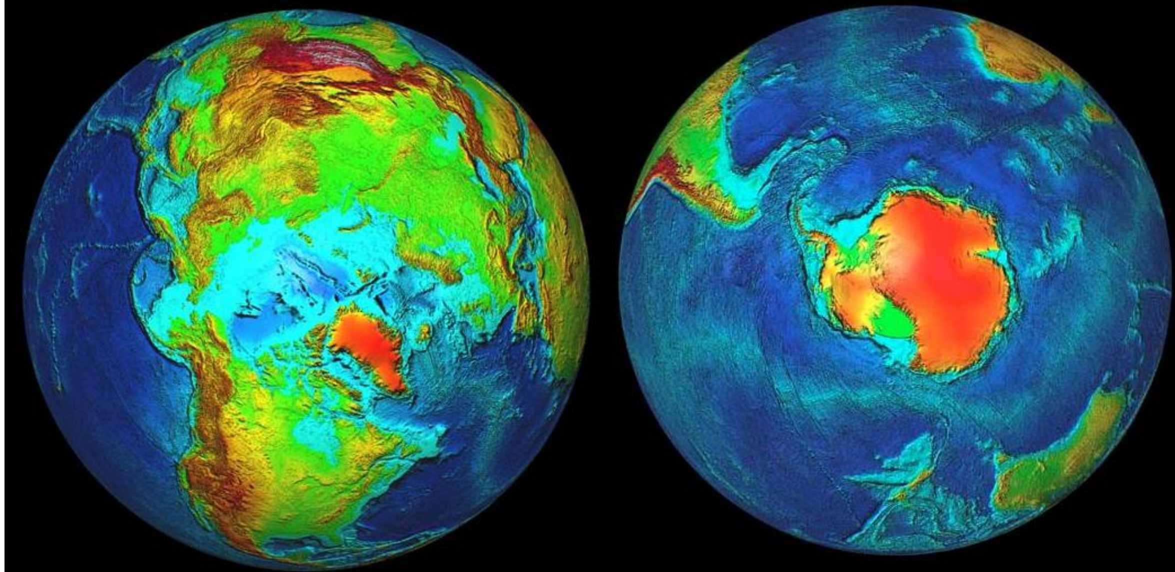
- **Location:** Christchurch, New Zealand
- **Event:** Pre- and Post Earthquake, February 2011
- **Stations:** Absolute Gravity (AG) and GNSS/GPS
- **Difference in Pre and Post Measurements:**
  - AG = - 6 μgal
  - GNSS = 16 millimeters (mm)
  - Vertical gravity gradient at this location is
    - -3.6 μgal/cm or 2.8 mm/μgal
  - Difference: AG - GNSS = 16.8 – 16 = < 1 mm



Thus, detected change in height by use of absolute gravity that agreed to within 1 mm of change measured with GNSS.

POLENET

http://www.polenet.org



Polar Earth Observing Network

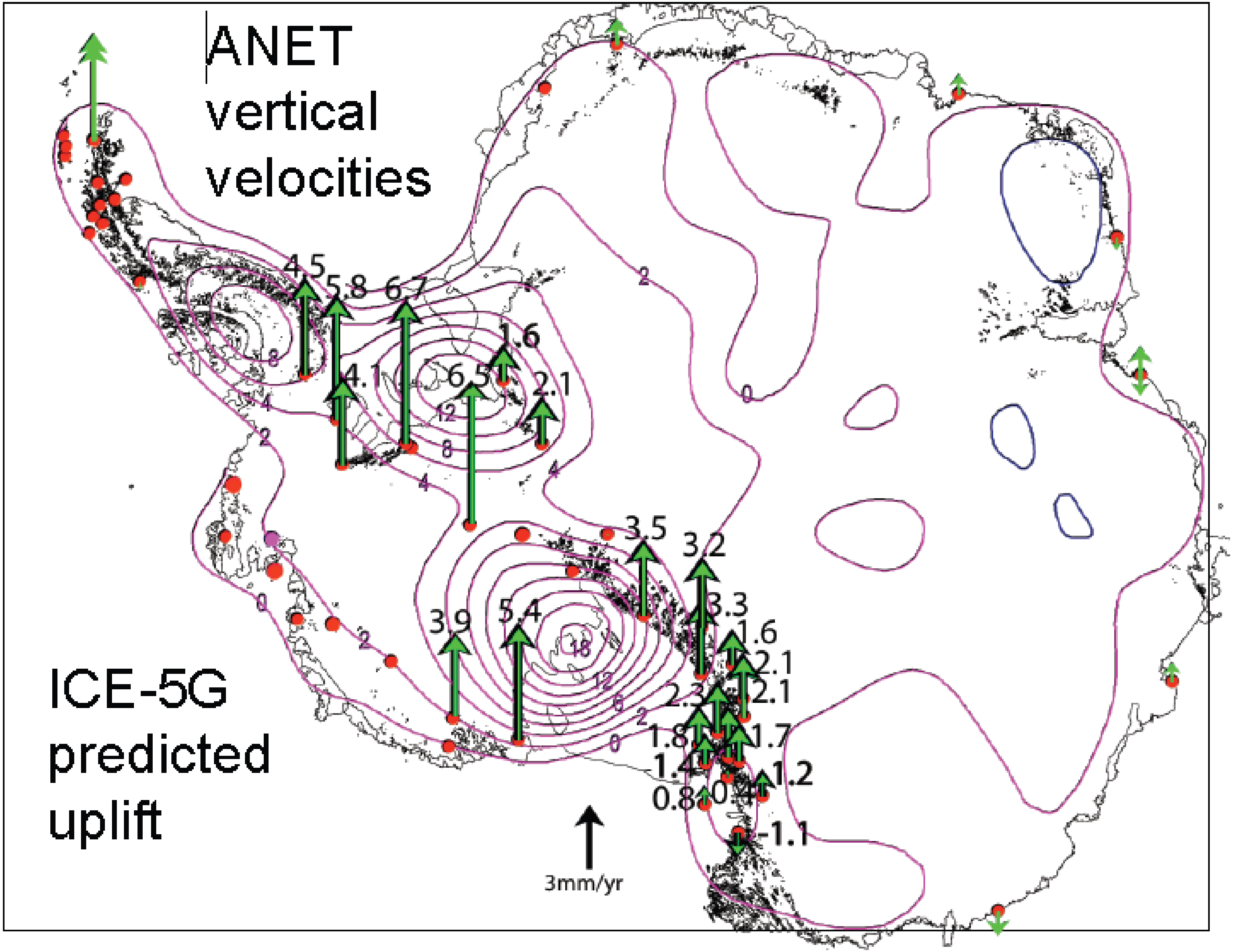
Principal Investigator: Dr. Terry Wilson, School of Earth Sciences, Ohio State University, Columbus

Polar Earth Observing Network

Geophysical Observatories

- ***GNSS (GPS+)***
- ***Seismic***
- ***Gravity: absolute and relative***

  Tide Gauges
- Geomagnetic
- Multisensor deep-sea observatories
- Space and airborne remote sensing measurements



ANET
vertical
velocities
ICE-5G
predicted
uplift
3mm/yr
4.5
5.8
6.7
1.6
4.1
6.5
2.1
3.5
3.2
3.3
3.9
5.4
1.6
2.1
2.1
2.3
1.8
1.7
1.4
1.2
0.8
0.4
-1.1