UNAVCO-AFFILIATED LATIN AMERICAN GEODETIC NETWORKS: OPERATIONS, SUSTAINABILITY & SCIENCE

M. Meghan Miller, President

UNAVCO, a non-profit university-governed consortium, facilitates geoscience research and education using geodesy.

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TODAY'S TOPICS

Geodetic Capabilities

- **Geodesy Toolbox for Geosciences**
- **Plate Boundary Observatory - a network of geodetic observing systems**
- **Key observables**

Modes of Deployment & Levels of Support

- UNAVCO-led community Networks
- UNAVCO-assisted PI Networks with different levels of support
  - O&M, network monitoring, data recovery, data management & archive
- GPS Seamless Archive Centers

Science Contributions & Emerging Opportunities

- Time-variant deformation
- Sensing Earth Environment
- Supporting a dynamic reference frame
- A new generation of InSAR - open Sentinel, NISAR observations and opportunities for GPS-InSAR integration
- GRACE Follow On
- Seafloor geodesy
- Federation of GPS Archives across the Americas

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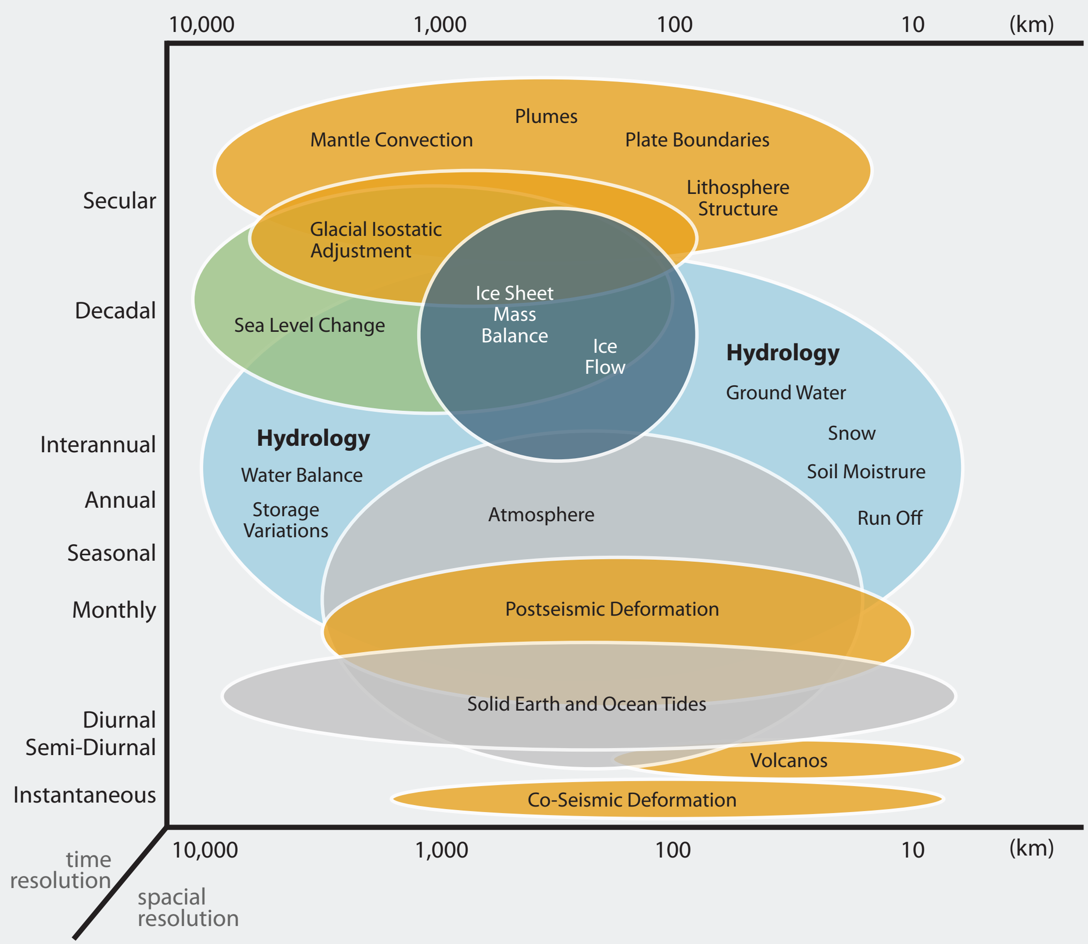
A GEODESY TOOL BOX FOR GEOSCIENCES



A GEODESY TOOL BOX FOR GEOSCIENCES

Point Observations:

GPS **Global Positioning System** *- 3D daily positions with sub-centimeter uncertainty in a dynamic global reference frame*

RTGPS **High Rate, Real Time GPS** *- 1 Hz or 5 Hz sample rate streaming with ~0.5 second latency, several centimeters uncertainty on epoch-by-epoch positions - local or global reference frame*

GNSS **Global Navigation Satellite Systems** *– International satellite navigation systems like GPS for positioning with global coverage (GLONASS, BEIDOU, GALILEO, IRNSS)*

GPS/Meteorology *- Integration of weather observations (Met Pack) with tropospheric water vapor GPS observations*

Tide Gauge-GPS Colocation *- Integration of water level measurements in a global reference frame*

GRACE-GPS Integration *- Integration of gravity observations with GPS ground control*

Geodetic imaging:

InSAR **Interferometric Synthetic Aperture Radar** *– differenced pairs of satellite radar images that map deforming zones such as faults, volcanoes, glaciers, and aquifers*

LiDAR **Light Detection and Ranging**

TLS **Terrestrial Laser Scanner** *– ground-based LiDAR, typically mounted on a tripod, providing very high-resolution imaging of small areas*

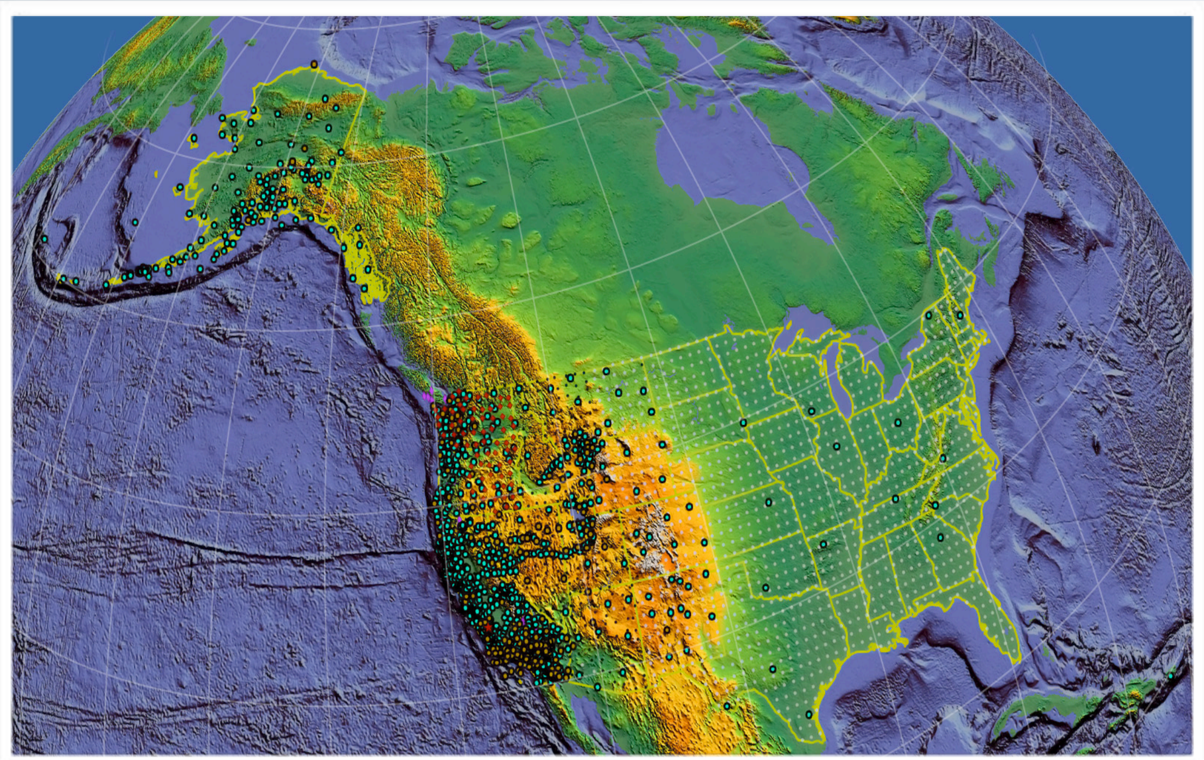
Borehole Geophysics:

Borehole Strainmeter *– measures the change in shape of a borehole at approximately 200 m depth with sensitivity at the scale of one ten-millionth of a human hair*

Borehole Seismometer *– measures ground deformation at very high frequencies with great sensitivity and is collocated with a borehole strainmeter in the Plate Boundary Observatory*

Tiltmeter *– measures the changing inclination of the Earth's surface over time, at a scale of one ten-thousandths of a degree*

EARTHSCOPE PLATE BOUNDARY OBSERVATORY

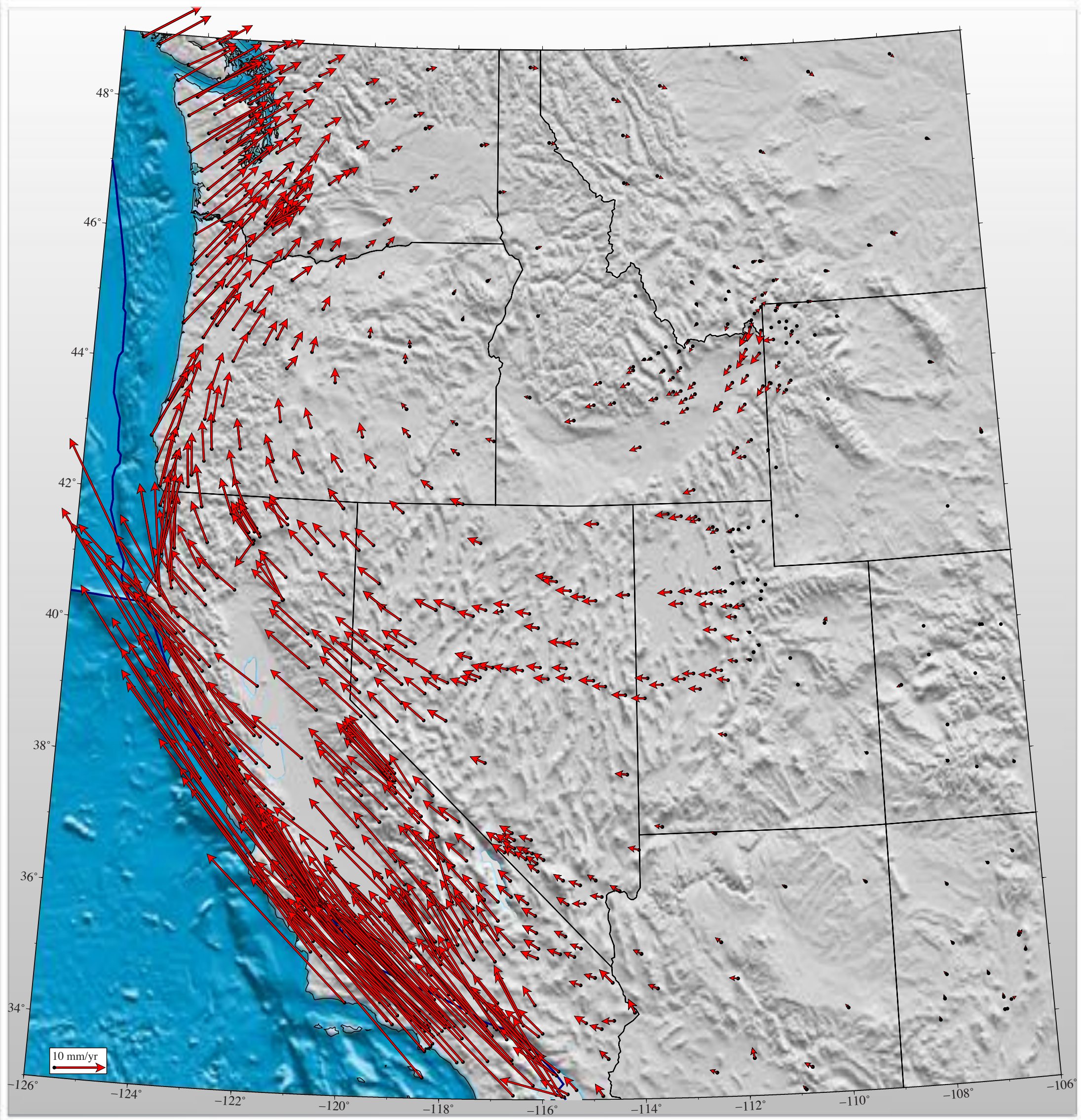


Integrating geodetic observations for full spectrum deformation characterization:

- 1,100+ cGPS
- ~400 RT-GPS
- collocated meteorologic observations
- Borehole systems combining:
  - 79 strain meter, seismometer ± pore pressure @ ~250 meters depth
  - 25 tilt meter in a shallow bore for inaccessible volcano settings
- Additional campaign & long-term GPS deployments
- Geodetic Imaging - GPS-InSAR
- Integration with USArray tomography

Science and impact goals:

- characterize the structure and evolution of the North American continent
- Provides civil Earth observations beyond science -
  - earthquake, volcano, hydrology & climate hazards
  - for surveying & reference frame products



KEY OBSERVABLES

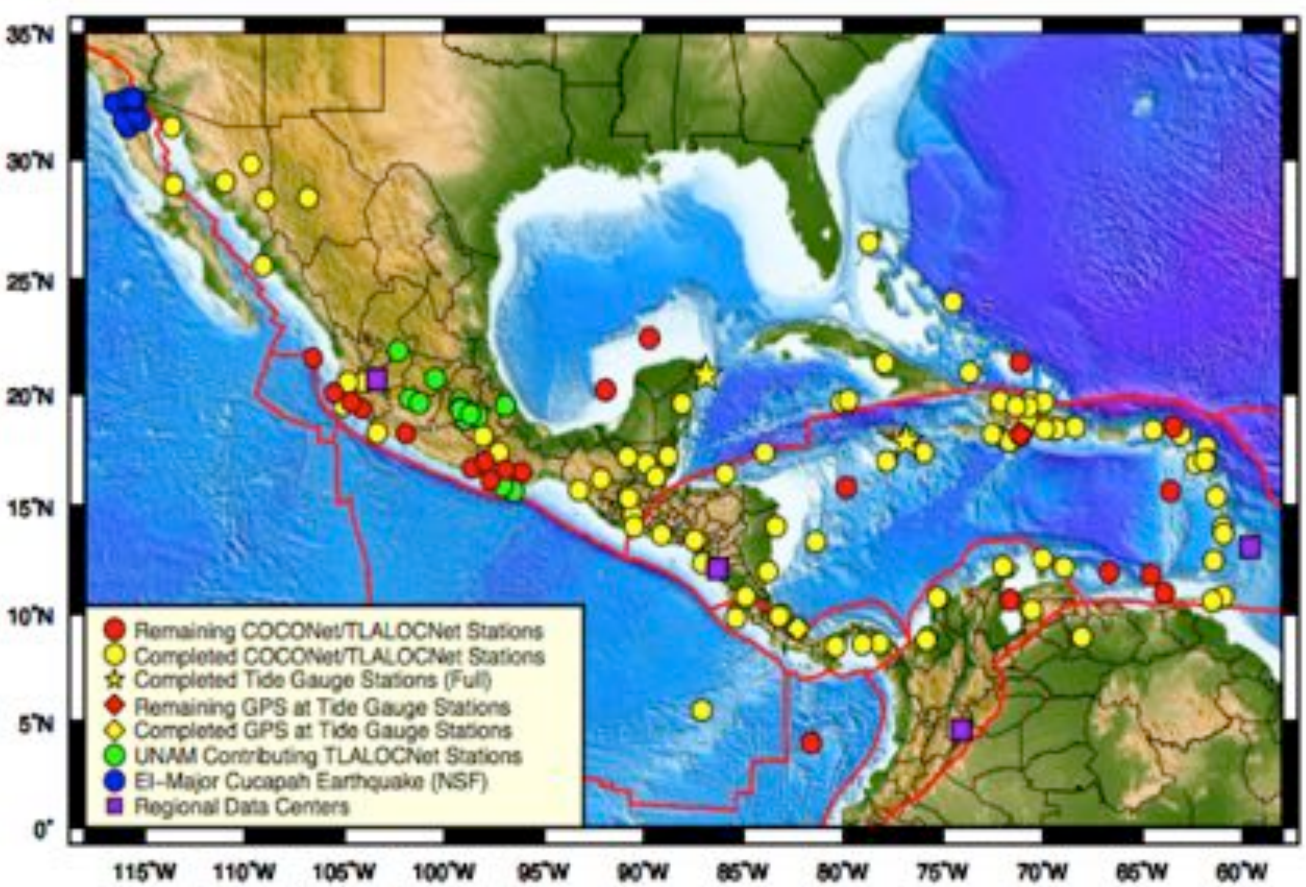
Ground deformation:

- 3D point motion - 5 Hz to daily, weekly positions, with sensitivities from mm to cm
- Borehole strain with nm sensitivity
- Seasonal and other periodic variations
- Episodic or protracted deformation events
- Velocity field

Environmental factors:

- Meteorological observations at the ground surface
- Soil moisture
- Vegetation index
- Water level, snow depth, and other changing reflective surfaces
- Precipitable water vapor in the troposphere
- Volcanic ash plumes
- Excitement of the ionosphere by solar storms, earthquakes, and tsunamis

TLALCOCNET & COCONET



Baja California RAPID

COCONet Plan: 83 New and Refurbished cGPS-Met Stations

COCONet Stations Completed: 71

COCONet Stations To Be Completed: 12

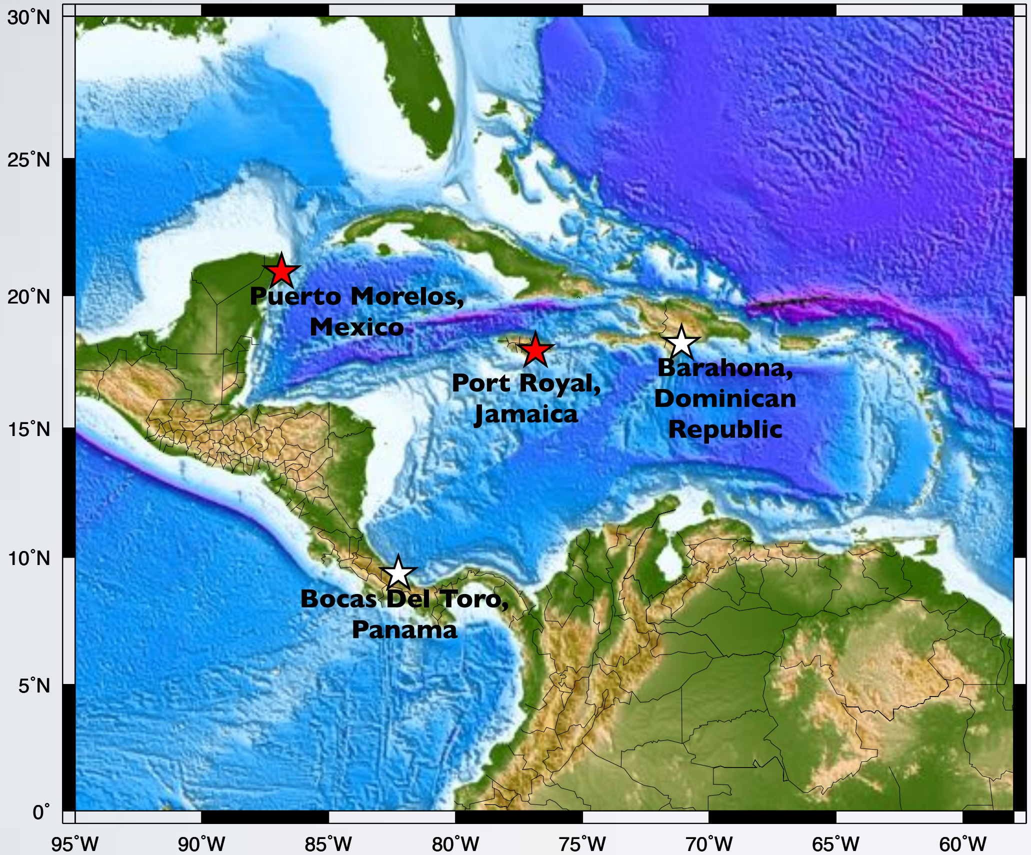
Tide Gauge Stations: 2

TLALOCNet Plan: 37 New and Refurbished cGPS-Met Stations (including UNAM stations)

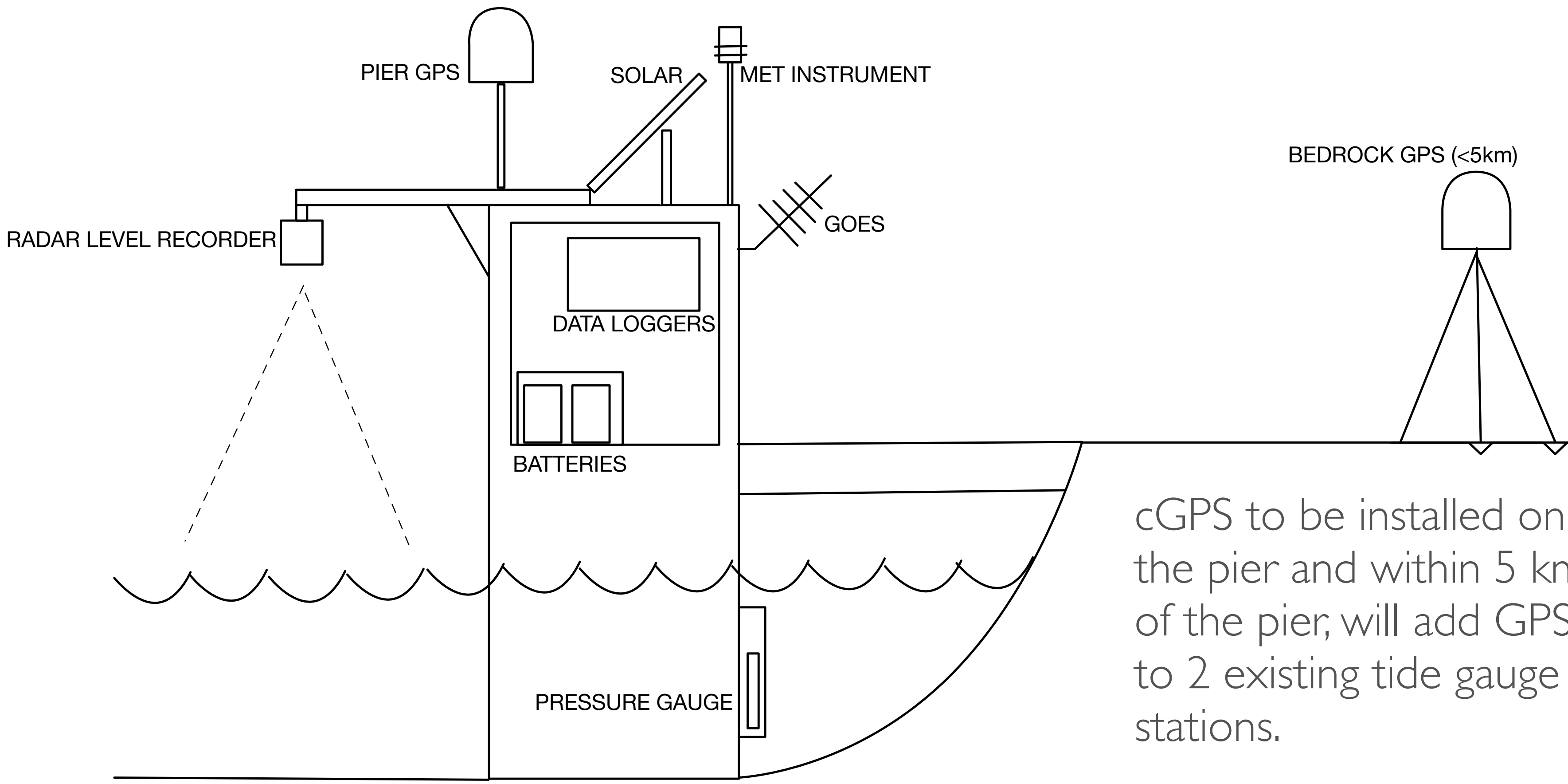
TLALOCNet Stations Completed: 14

TLALOCNet Stations To Be Completed: 23 (11 UNAVCO, 12 UNAM)

SEA LEVEL STATION LOCATIONS



GPS CONSTRAINED TIDE GAUGE STATION LAYOUT



cGPS to be installed on the pier and within 5 km of the pier, will add GPS to 2 existing tide gauge stations.


UNAM
Instituto de Ciencias
del Mar
y Limnología
UNIDAD ACADÉMICA
PUERTO MORELOS

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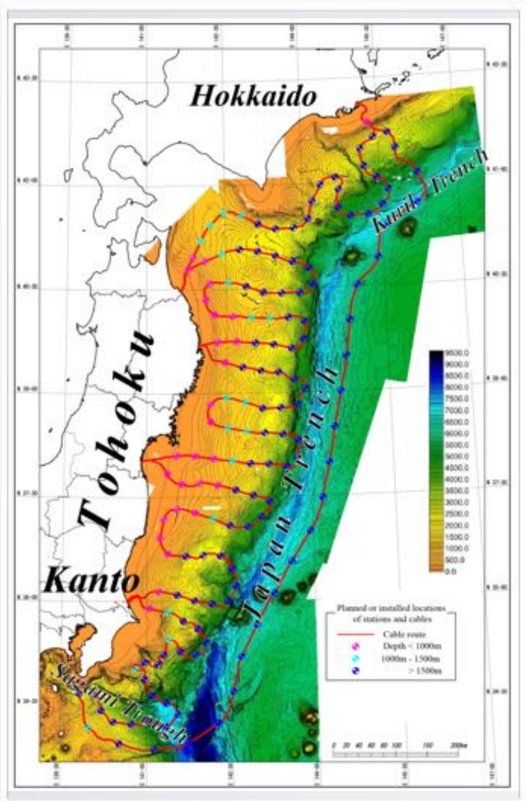
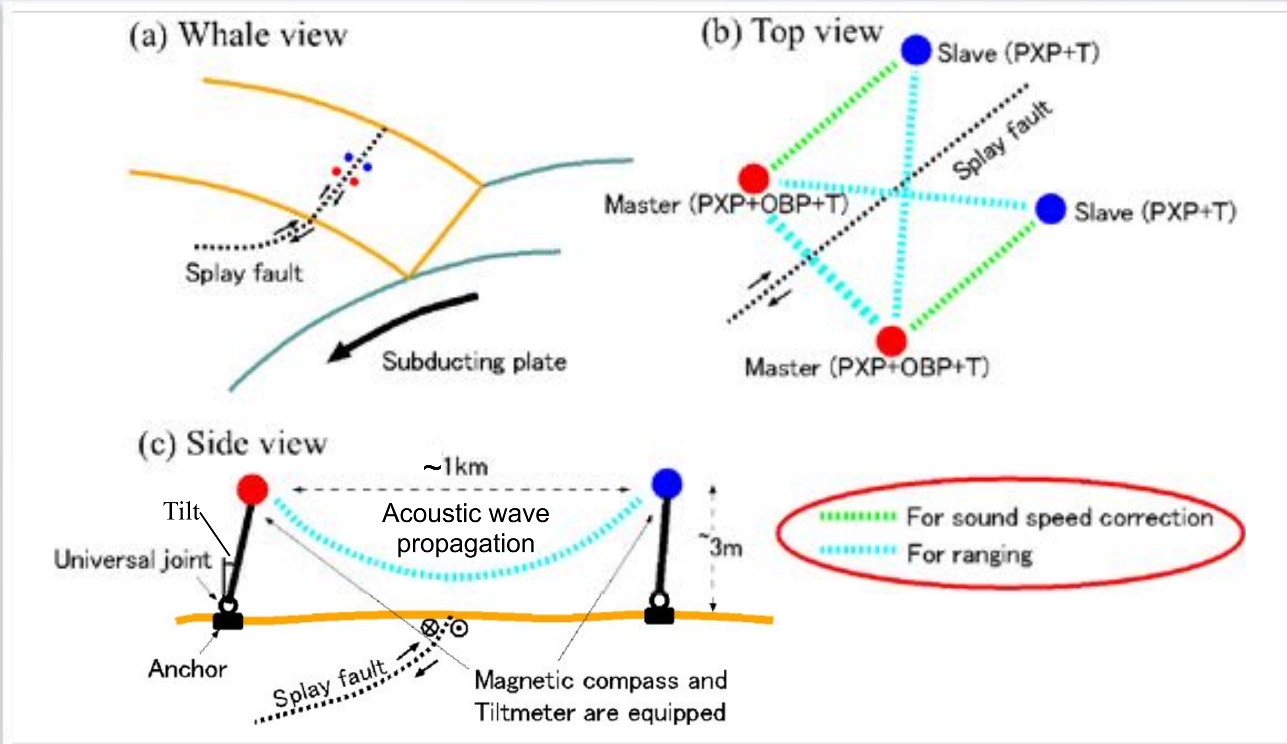
SEA LEVEL STATION PUMO2 INSTALLATION

COCONET VELOCITY FIELD

Seafloor Geodetic Approaches to Subduction Thrust Earthquakes

Fujimoto
2013





- **Seafloor geodesy system**
- **S-cable deployment**

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Modes of Deployment & Levels of Support

- **UNAVCO-led community Networks**
- **UNAVCO-assisted PI Networks with different levels of support**
  - **O&M, network monitoring, data recovery, data management & archive - Rapid response**
- **Network of Geodetic Networks for the Americas**

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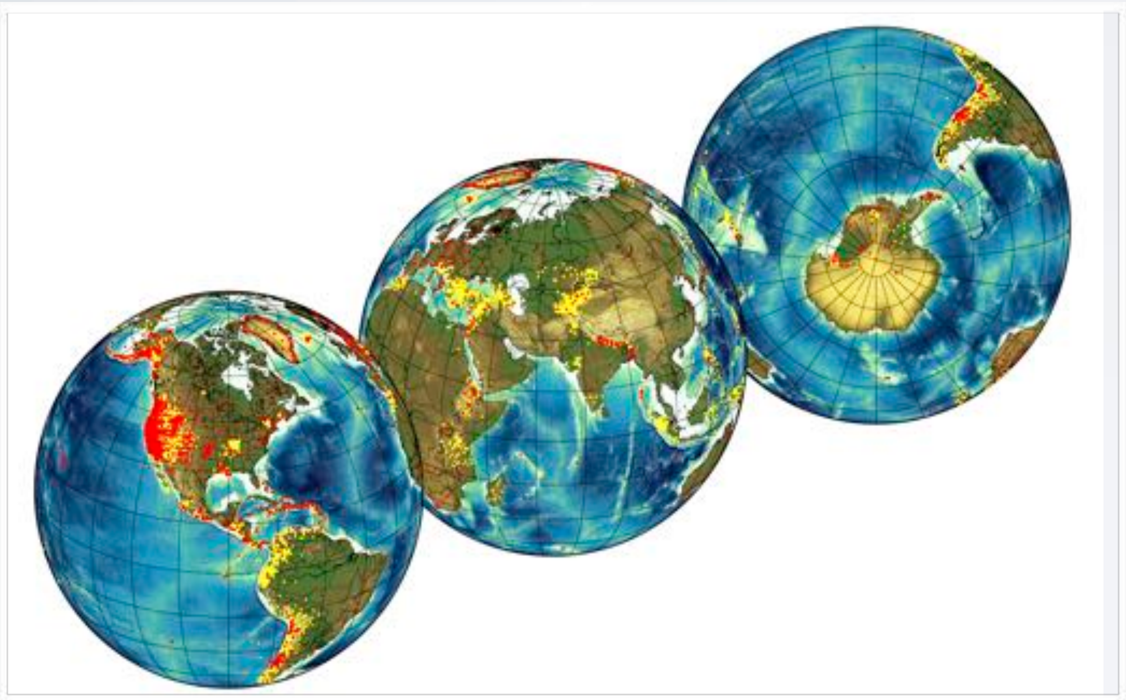
Levels of Support for Community Networks



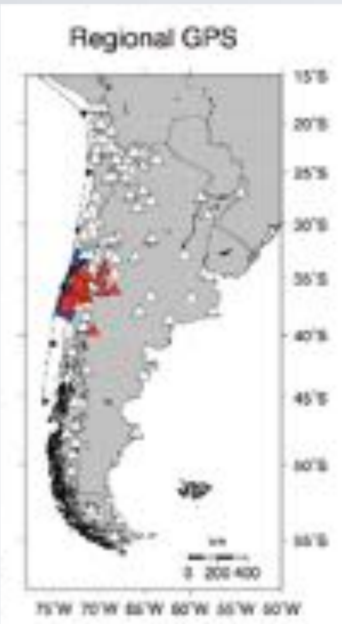
- **High** – UNAVCO Facility provides **centralized O&M support** that may include **retrieving the data, monitoring station data flow, and proactively responding to problems with data flow or station hardware**. Problems are fixed remotely working with collaborators if necessary. If maintenance trips or materials are required for O&M, these are funded by the PI's project.

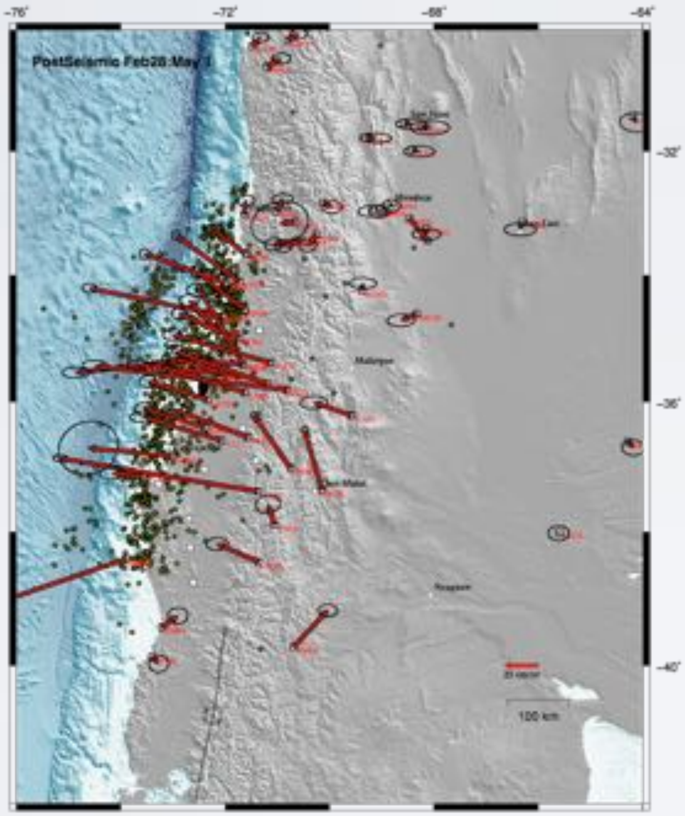
- **Medium** – PIs or collaborators download the data from the stations, monitor station data flow, and handle most problems themselves. **UNAVCO provides engineering and medium-level technical support on a request basis.** Any UNAVCO Engineering maintenance trips and materials required for O&M are covered by the PI's project.

- **Low** – UNAVCO provides **only archiving support and a low-level of technical support**. UNAVCO does not monitor or download data from the stations.

Maule, Chile Mw = 8.8 February 27, 2010 NSF-RAPID UNAVCO GPS Field Deployments

Large-scale multi-national, multi-institutional collaboration to install 25 temporary GPS stations in 4 weeks following the earthquake





- Instituto Geográphico Militar (Chile)
- Universidad de Concepción (Chile)
- Universidad de Chile
- Instituto Geográphico Nacional (Arg.)
- Universidad Nacional de Cuyo (Arg.)
- UNAVCO (USA)
- Ohio State University (USA)
- University of Hawaii (USA)
- University of Memphis (USA)
- Caltech (USA)

- Three $200,000 NSF RAPID Proposals
- Funded in March, April 2010 to three PI's
- UNAVCO equipment utilized
- Involving 10 Government and academic institutions from the USA, Chile, and Argentina.

In 2011 the stations were made permanent under NSF I&F funding

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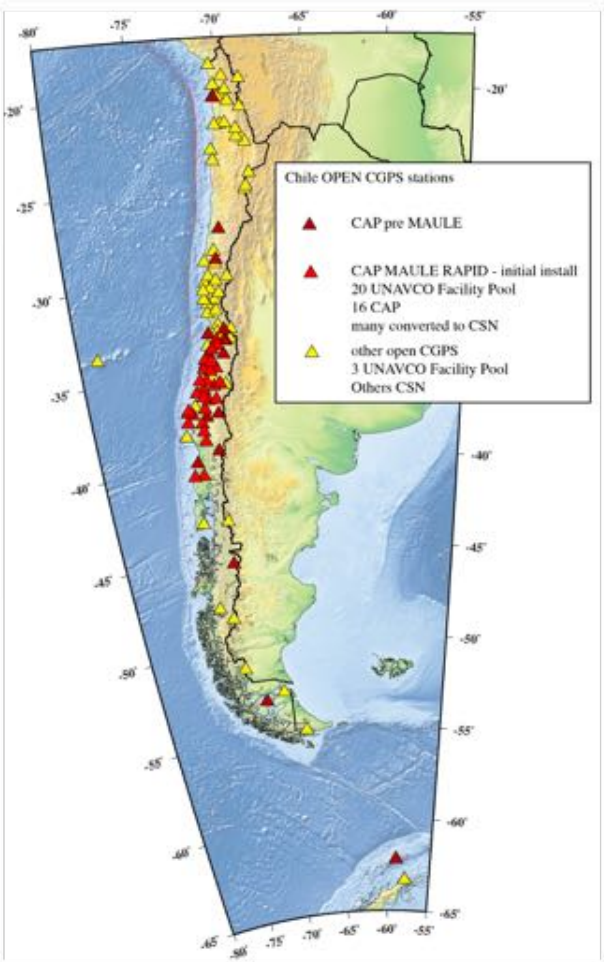
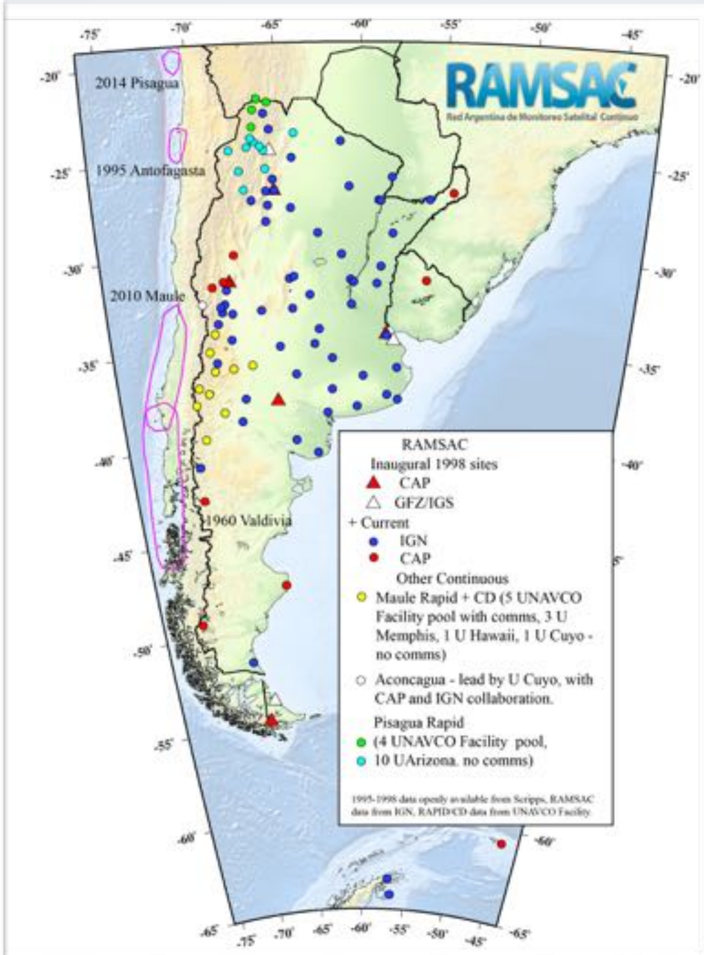
Coordinated Observations - Maule





EAR- RAPID - GPS Observations in Chile of Co-seismic and Post-seismic Deformation Associated with the 27 Feb, 2010 Mw 8.8 Maule, Chile Earthquake

EAR-- RAPID: GPS Observations in Argentina of Co-seismic and Post-seismic Deformation Associated with the 27 Feb, 2010 Mw 8.8 Maule, Chile Earthquake

EAR-- RAPID - Data Communications Support for GPS Observations of Crustal Deformation Associated with the 2010 Chile Earthquake

EAR-- Continental Dynamics: Collaborative Research: Great Earthquakes, Megathrust Phenomenology and Continental Dynamics in the Southern Andes
For the upgrade of 25 cGPS stations in Chile and Argentina, including purchase of new GNSS receivers and antennas, and associated field costs.

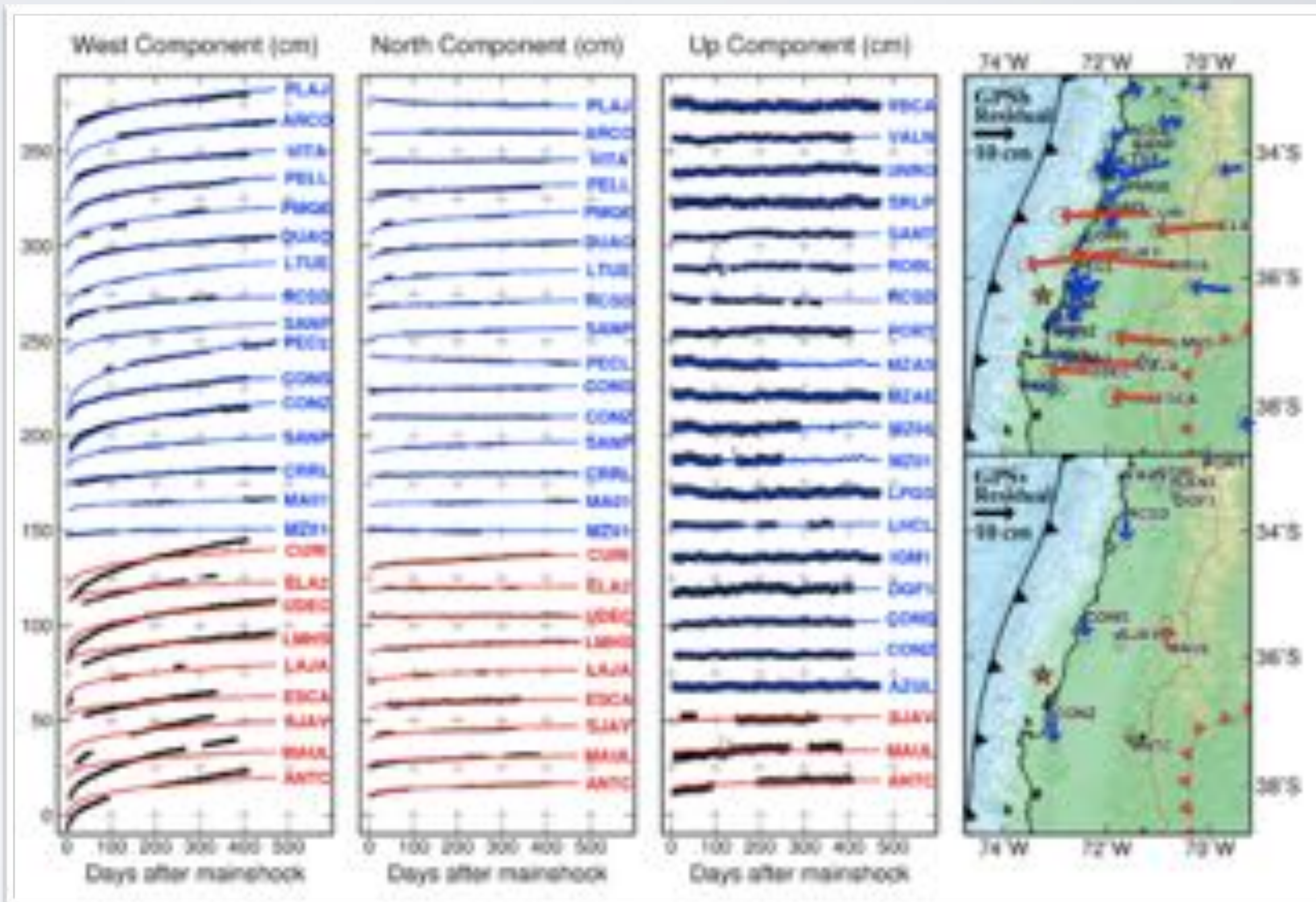
Organizations and institutions involved: UNAVCO, University of Hawaii, The Ohio State University, University of Memphis, California Institute of Technology, Universidad de Chile, Santiago, Universidad de Concepción, Insititúto Geográphico Militar de Chile, Instituto Geográphico Nacional de Argentina, Universidad Nacional de Cuyo Argentina.

Number of people involved: > 100

See Smalley Poster

Maule earthquake co-seismic & post-seismic deformation

Lin,[1]
Sladen,[2]
Ortega-Culaciati,[1]
Simons,[1]
Avouac,[1]
Fielding,
Brooks,[4]
Bevis,[5]
Genrich,[1]
Rietbrock,[6]
Vigny,[7]
Smalley,[8] &
Socquet[9]
2013



GSAC IMPLEMENTATION ABROAD

DATAWORKS FOR GNSS

- Software and hardware solutions for managing GNSS data flow and metadata
- Developed under COCONet and TLALOCNet by UNAVCO for international collaboration
- Regional Data Centers established in Barbados, Colombia, Mexico, and Nicaragua
- Training conducted in December 2014

GSAC - GNSS Seamless Archive Centers

- For data discovery, access and interaction, initially among three U.S. NASA archives
- Based on shared metadata
- The holdings of all archives are visible from each
- Implementation now extended to key European partners

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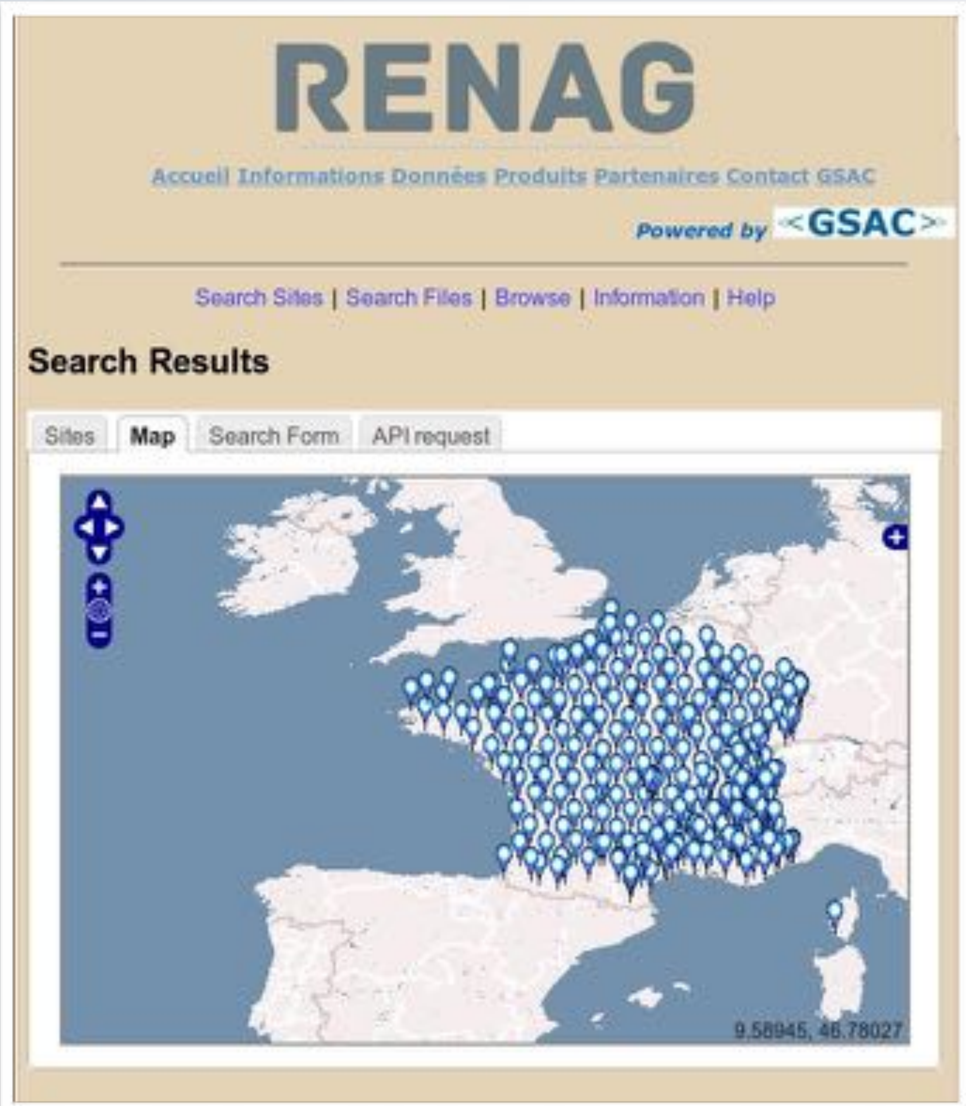

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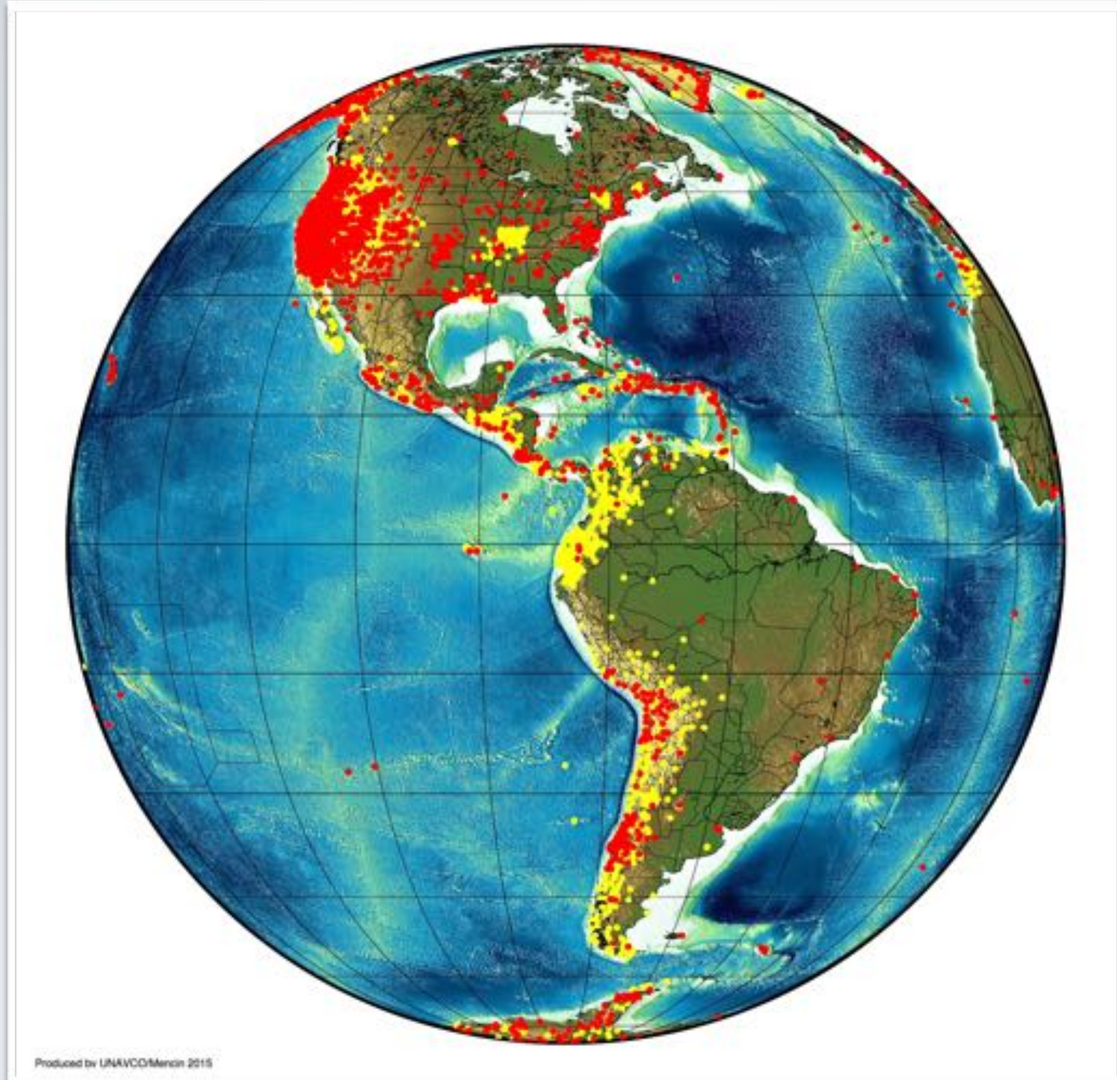

NETWORK OF GEODETIC NETWORKS FOR THE AMERICAS

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Network of Geodetic Networks for the Americas -

- UNAVCO seeks additional key partners for western hemisphere-scale implementation
- Collaborative development and dissemination of tools for data management, archiving and distribution

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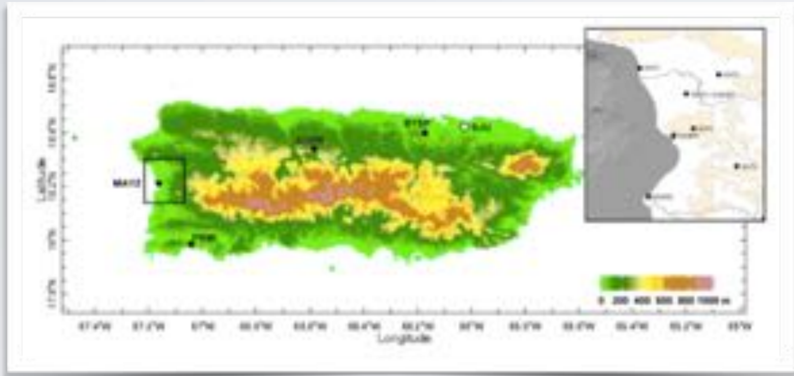
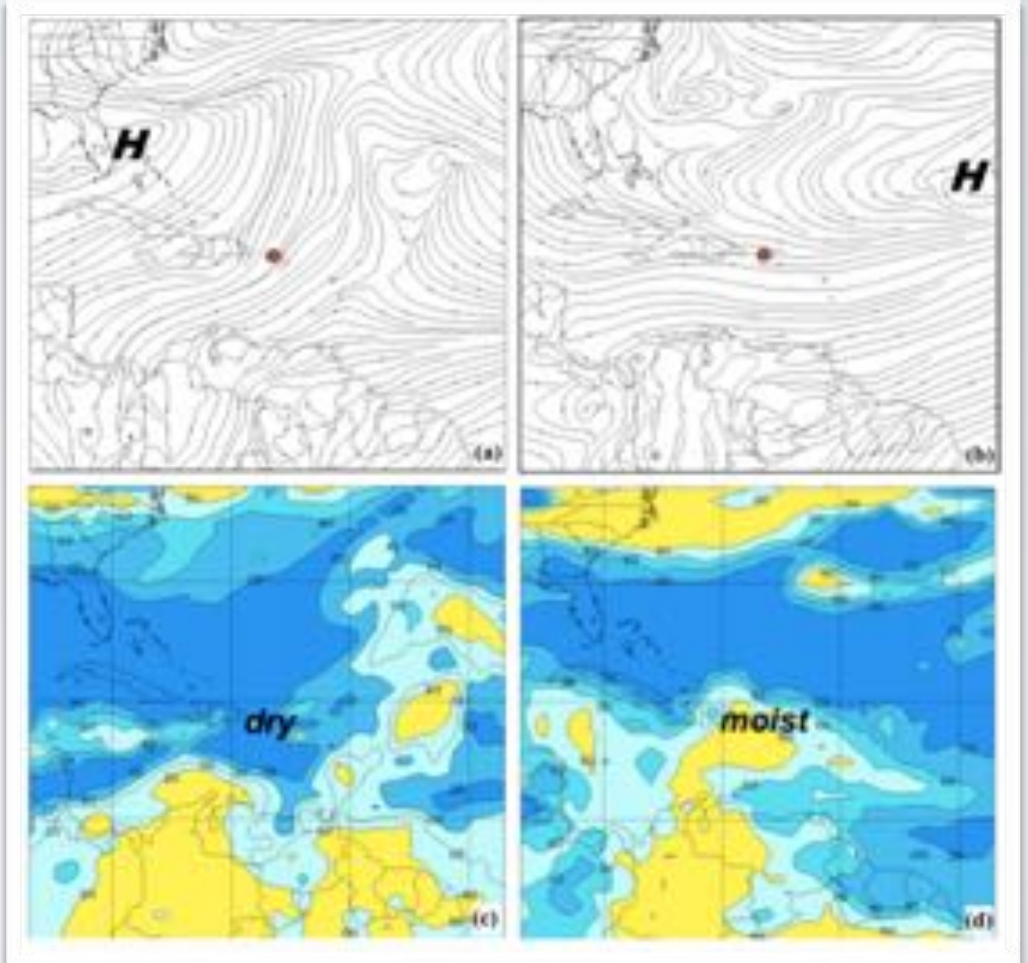
INFLUENCE OF TOPOGRAPHY AND THERMAL CIRCULATIONS ON MOISTURE IN THE ATMOSPHERE

Villamil-Ortero, Meiszberg, Haase, Min, Jury, Braun, 2014

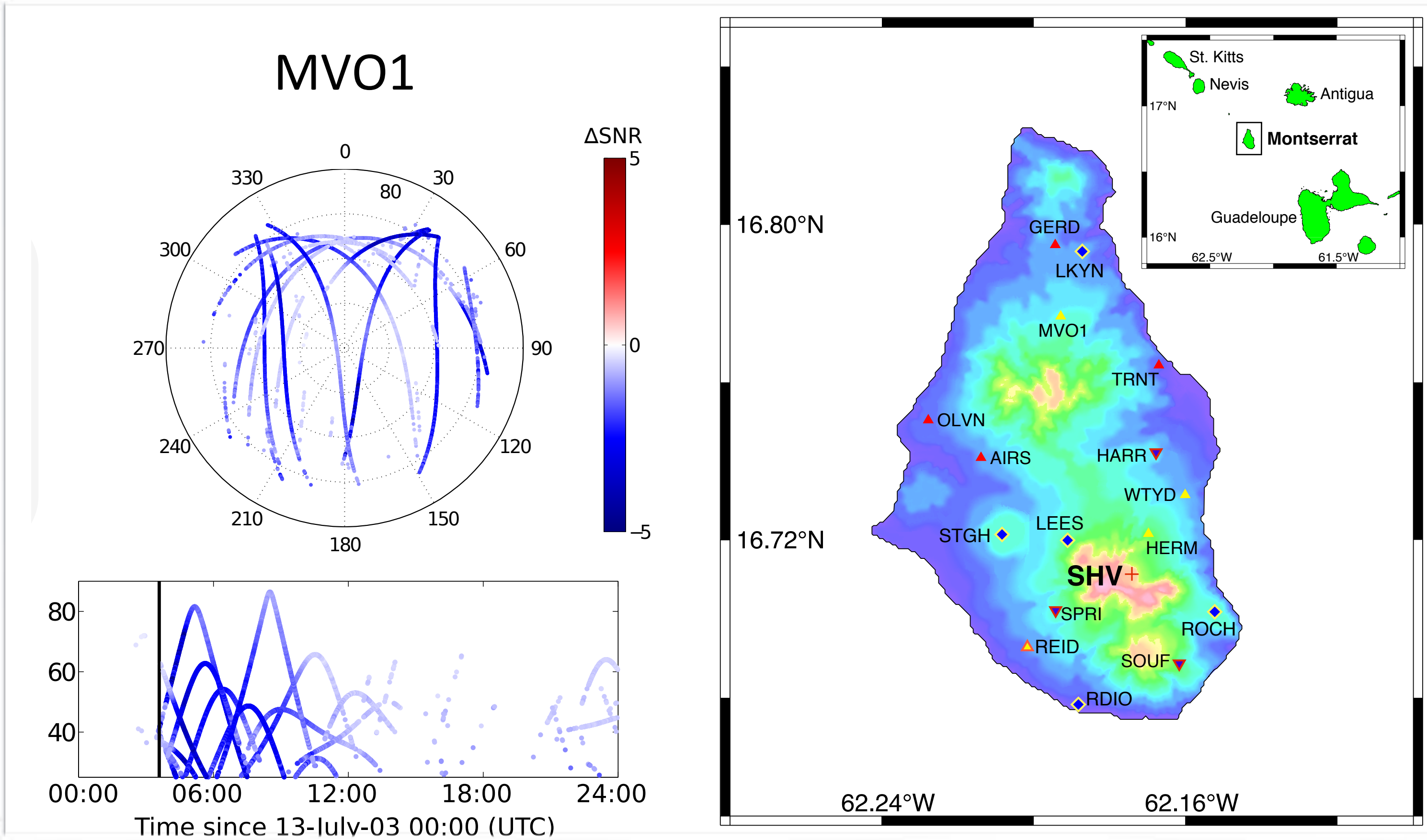




- educational research for 14 students from University of Puerto Rico and Purdue University
- circulation and moisture from GPS and meteorological observations
- common onshore westerly flow of 4 m/sec - thermally driven sea breeze with twin gyres that form a wake
- diurnal cycling of precipitable water (PW)
- widespread uplift reflects water loss
- WRF model overestimates PW in the west - evapotranspiration as a mechanism?
- convective instability leads to local rainfall

GPS DETECTION OF ASH PLUMES AND VERTICAL DEFORMATION DURING THE JULY 2003 DOME COLLAPSE: SOUFRIÈRE HILLS VOLCANO, MONTSERRAT

Medina, Mattioli, Braun, 2013



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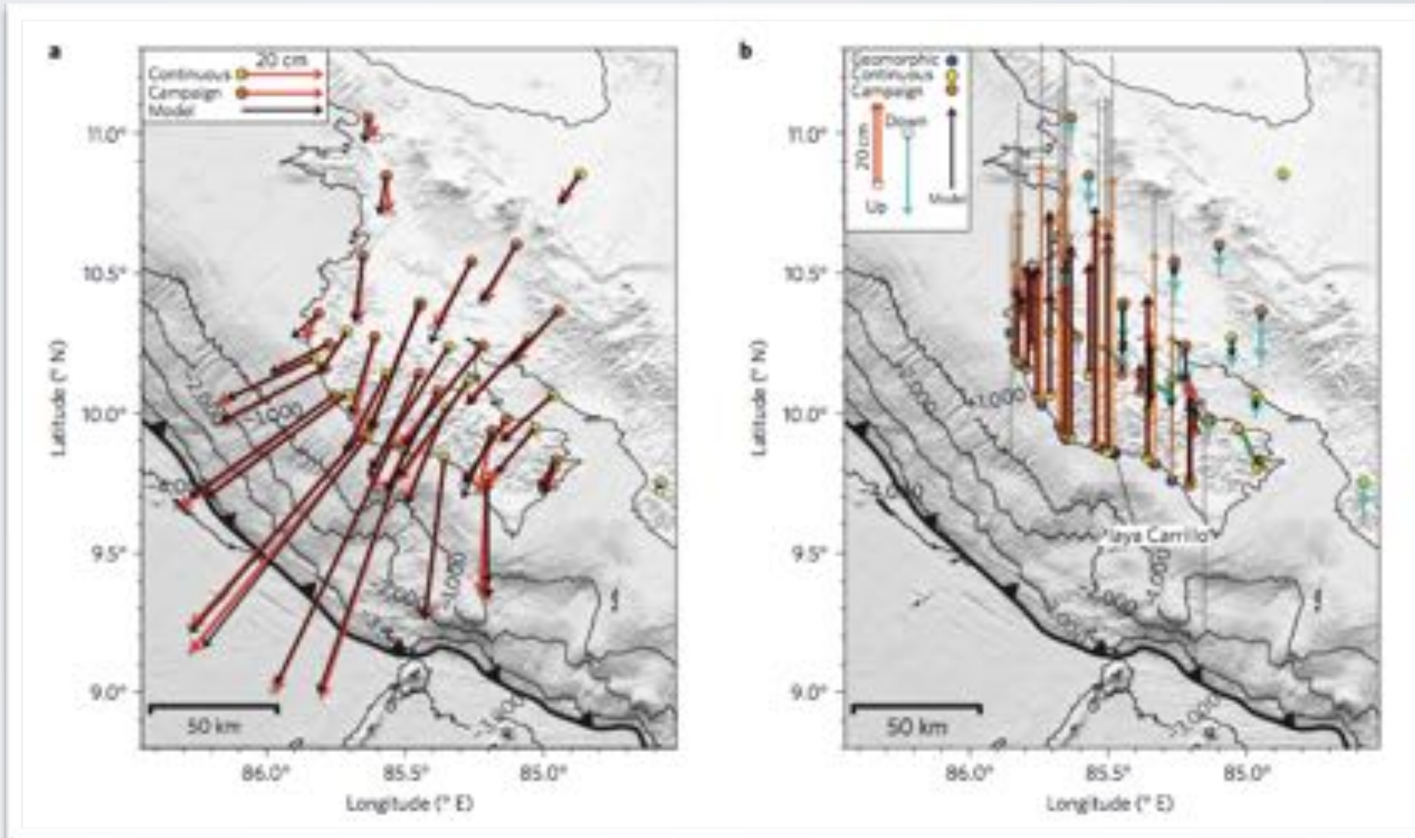
Nicoya earthquake rupture anticipated by geodetic measurement of the locked plate interface

Protti, González, Newman, Dixon, Schwartz, Marshall, Feng, Walter, Malservisi & Owen 2012

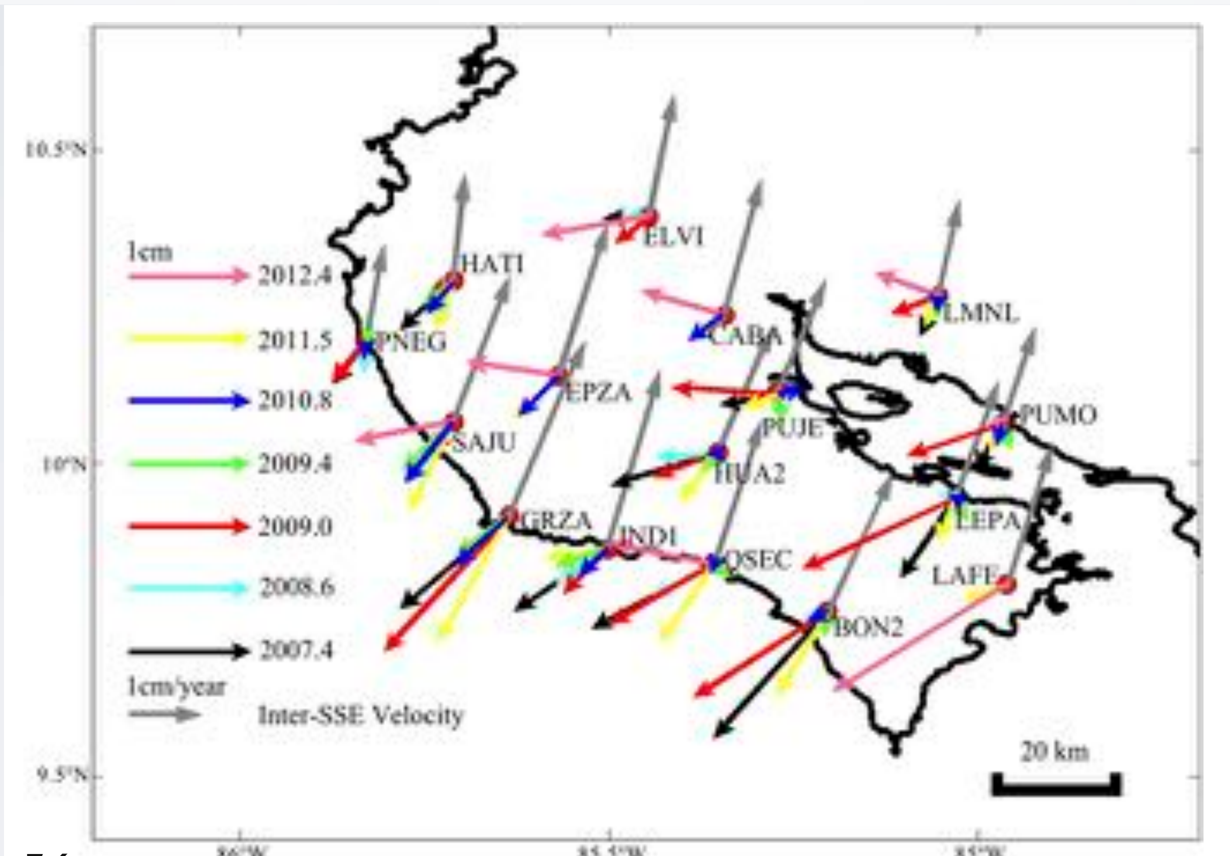


- **1853, 1900, 1950 & 2012**
- **Mw 7.6 Nicoya ruptured locked portion**
- **Previously locked region offshore**
- **pairing of locking extent & subsequent co-seismic rupture by near-field geodesy contrains future earthquake potential**
- **it is exceedingly useful to have a subaerial forearc!**

Earthquake and tsunami forecasts:

Relation of slow slip events to subsequent earthquake rupture

Dixon, Jiang, Malservisi, McCaffrey, Voss, Protti & Gonzalez 2014



- September 5, 2012 Mw 7.6
- Rich history of preceding SSEs release significant inter seismic strain
- Constrain a map of slip deficit that controlled the seismic rupture

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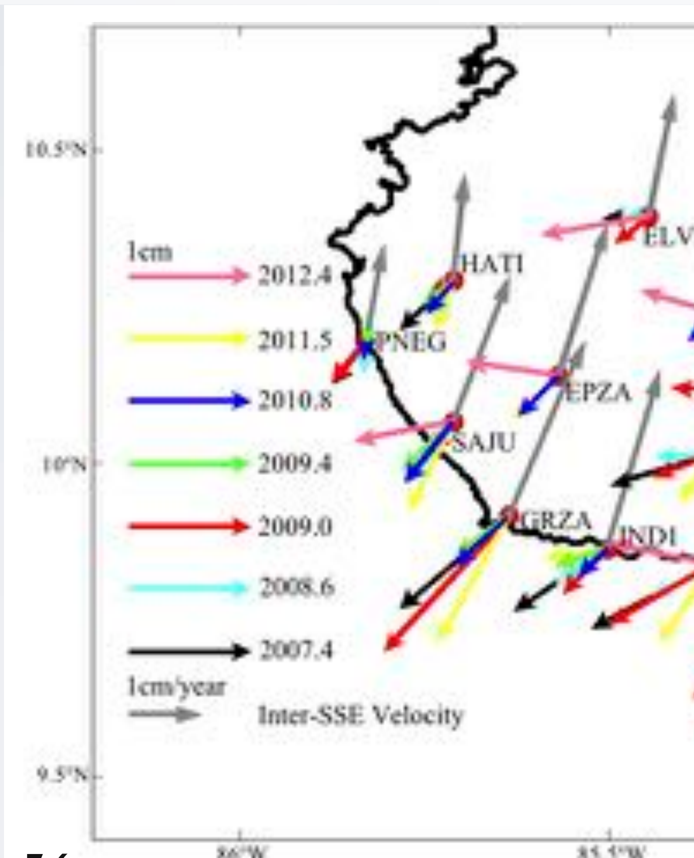

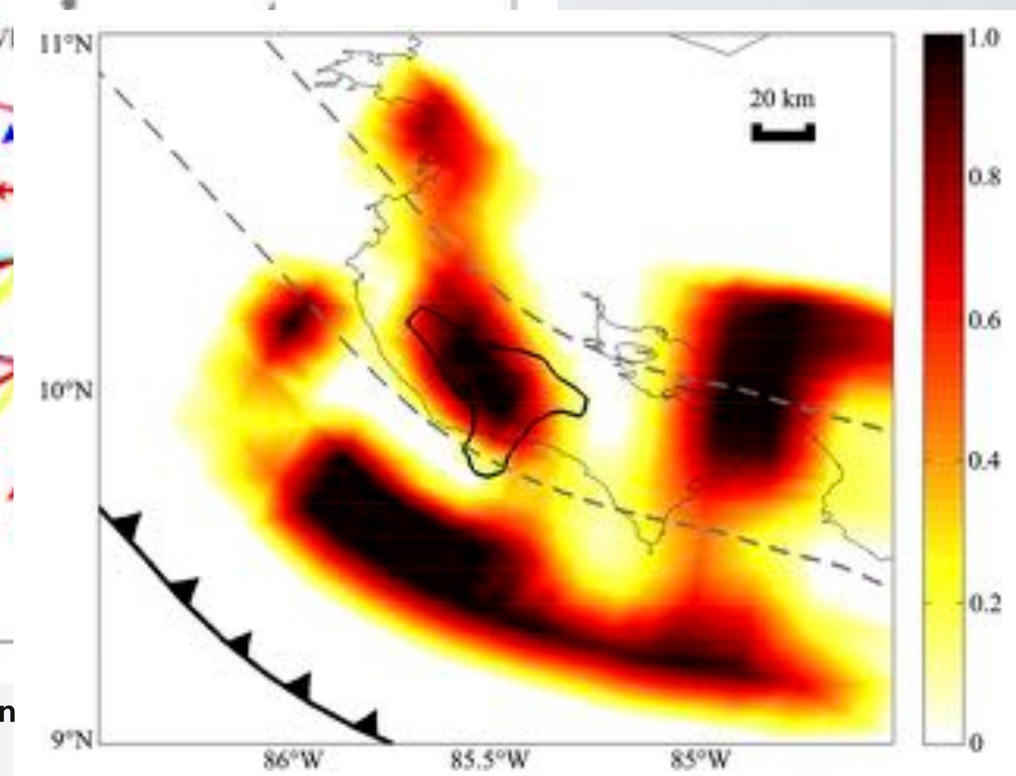

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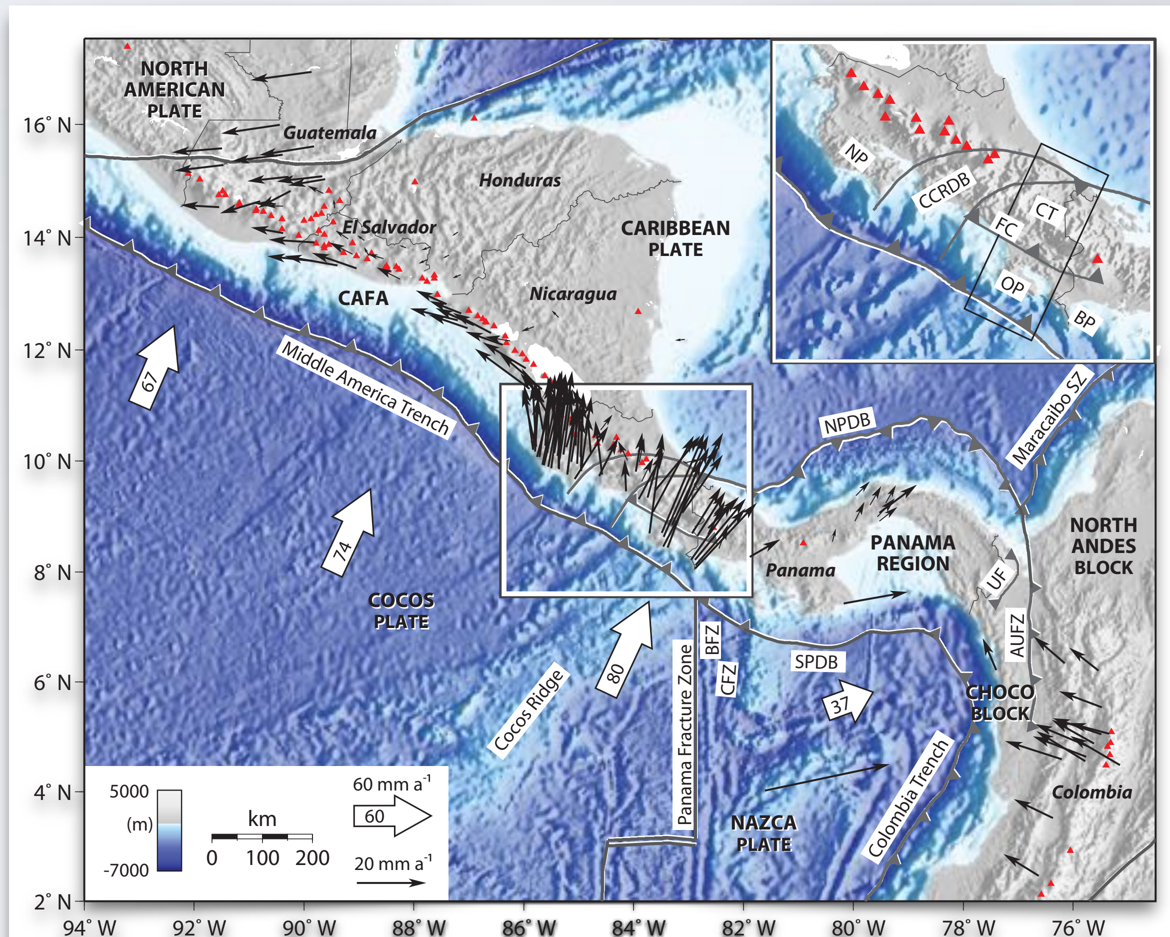
KINEMATICS OF THE WESTERN CARIBBEAN: COLLISION OF THE COCOS RIDGE AND UPPER PLATE DEFORMATION

Kobayashi[1,2], LaFemina[1], Geirsson[1], Chichaco[3], Abrego[4], Mora[5], and Camacho[3]
2015



- **Cocos Ridge collision disrupts Caribbean plate**
- **shortening, segmentation & fore arc escape**
- **GPS constraints set in a Caribbean plate context**

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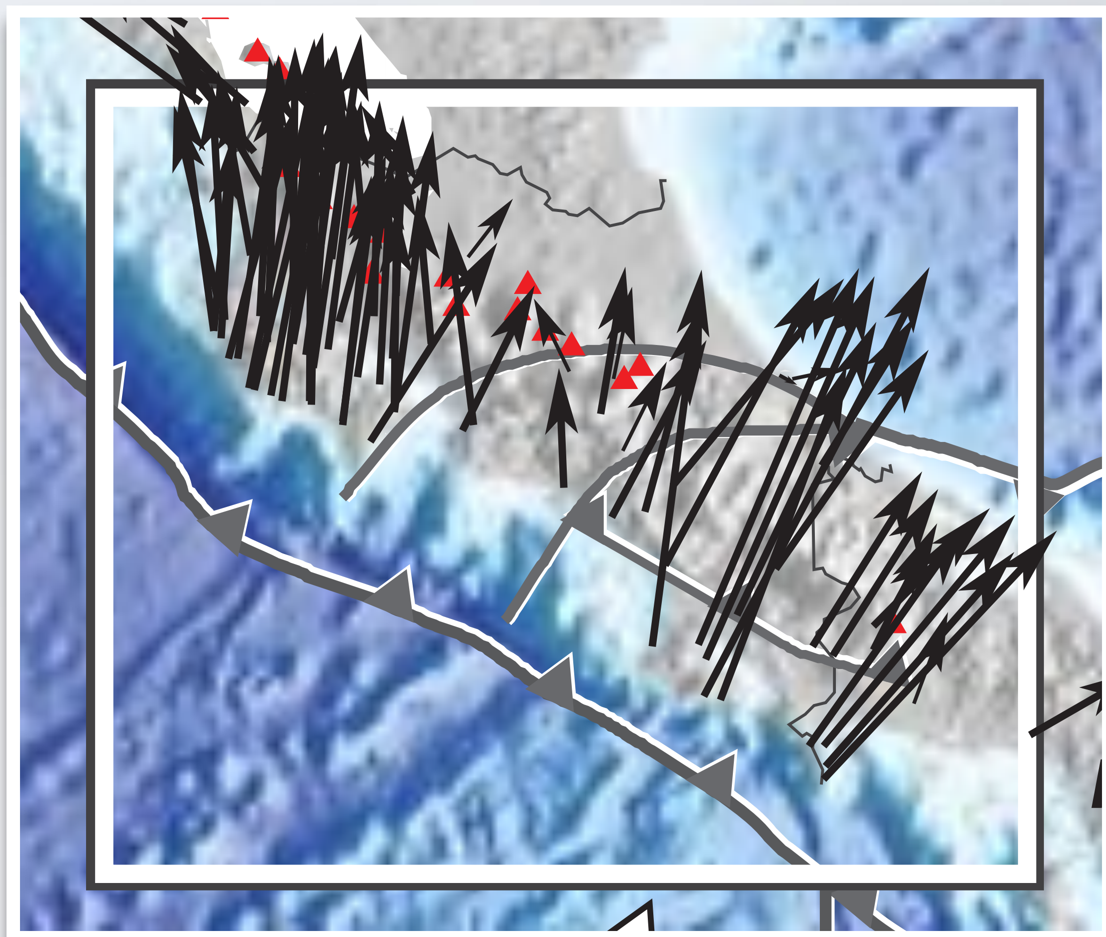

- Cocos Ridge collision disrupts Caribbean plate
- shortening, segmentation & fore arc escape
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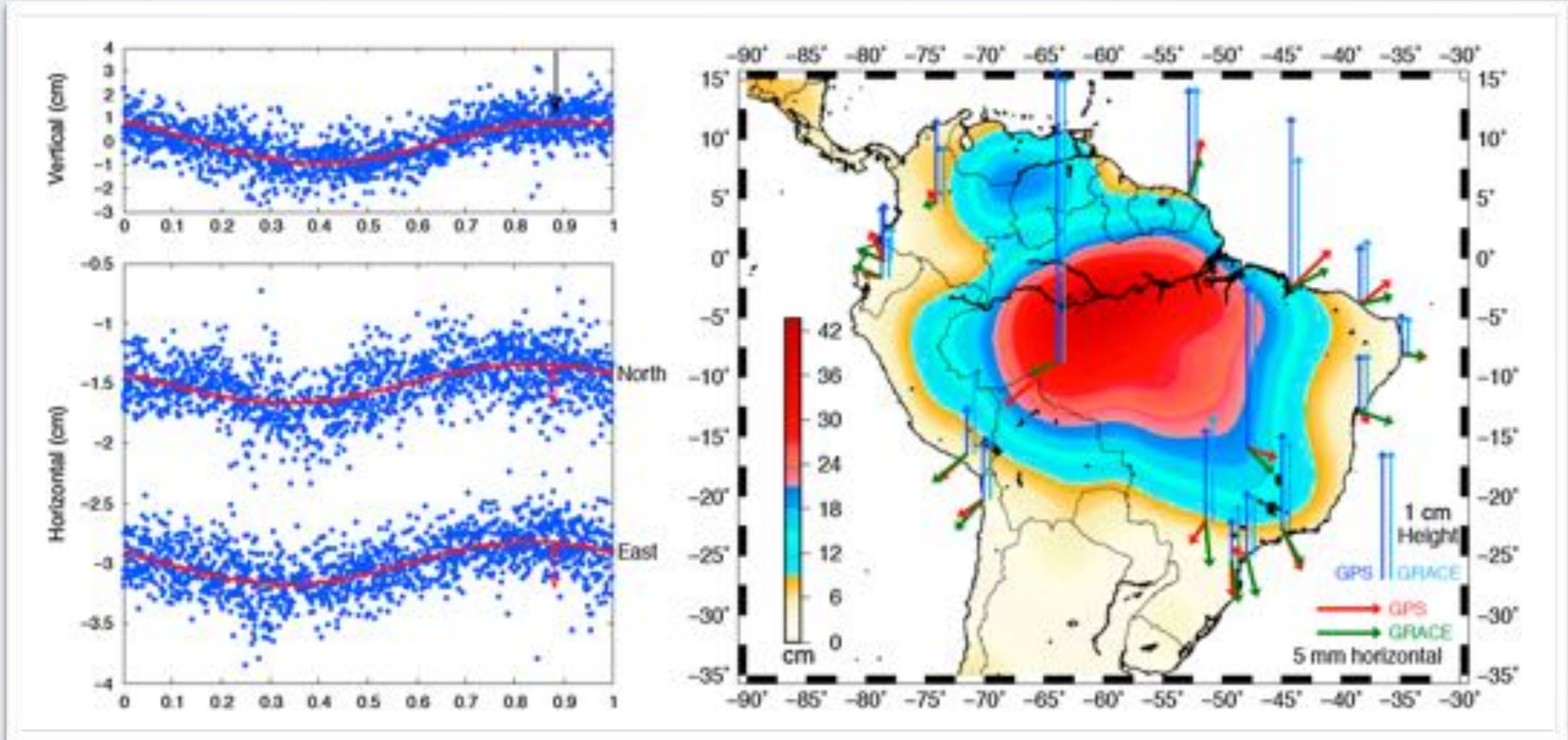
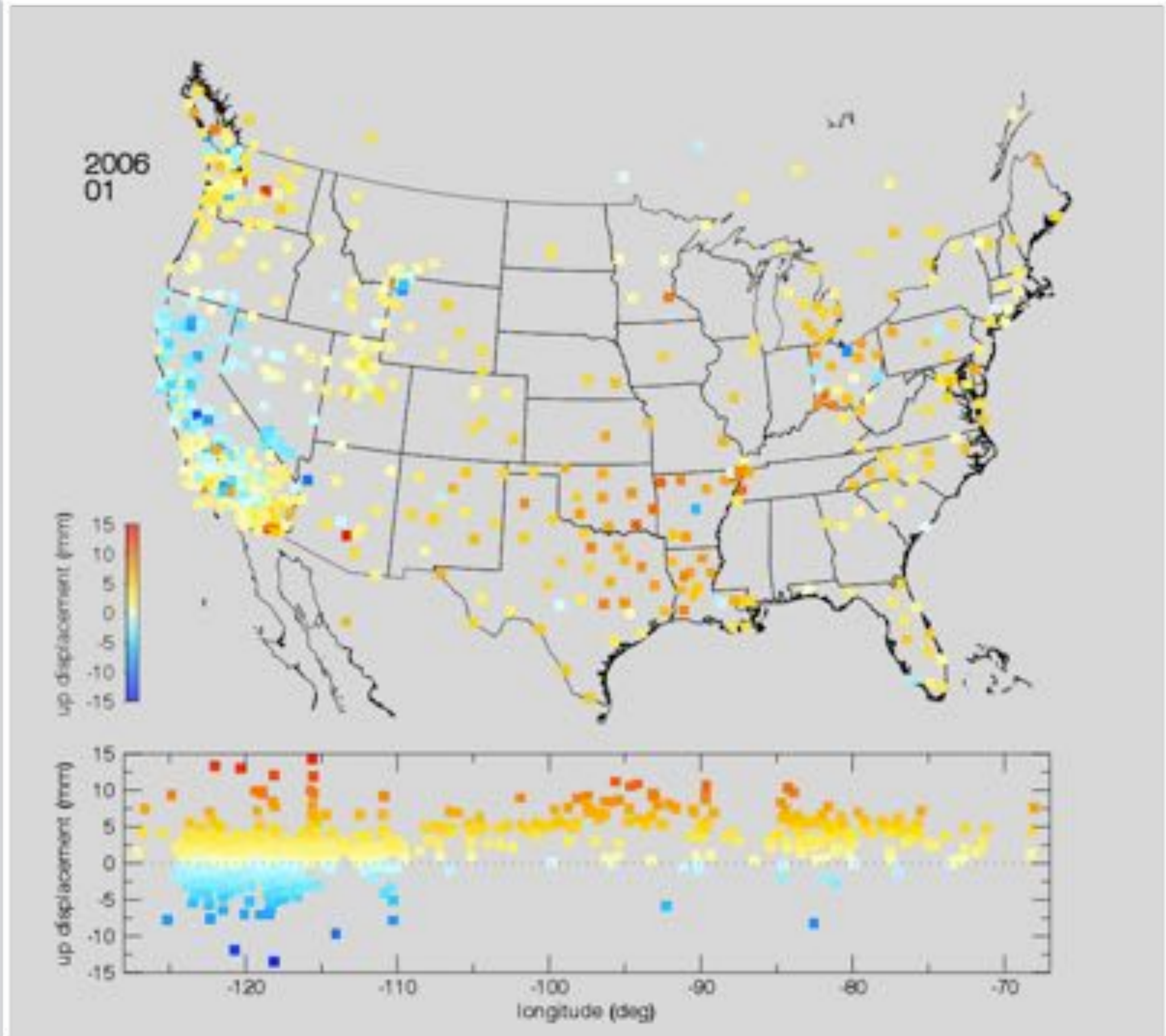
SEASONAL WATER STORAGE

- GRACE and GPS constrain seasonally Solid Earth motion
- Towards the Amazon in the spring
- Towards SE Asia during summer monsoons



Fu, Freymueller, 2013

Borsa, Agnew, & Cayan, 2014

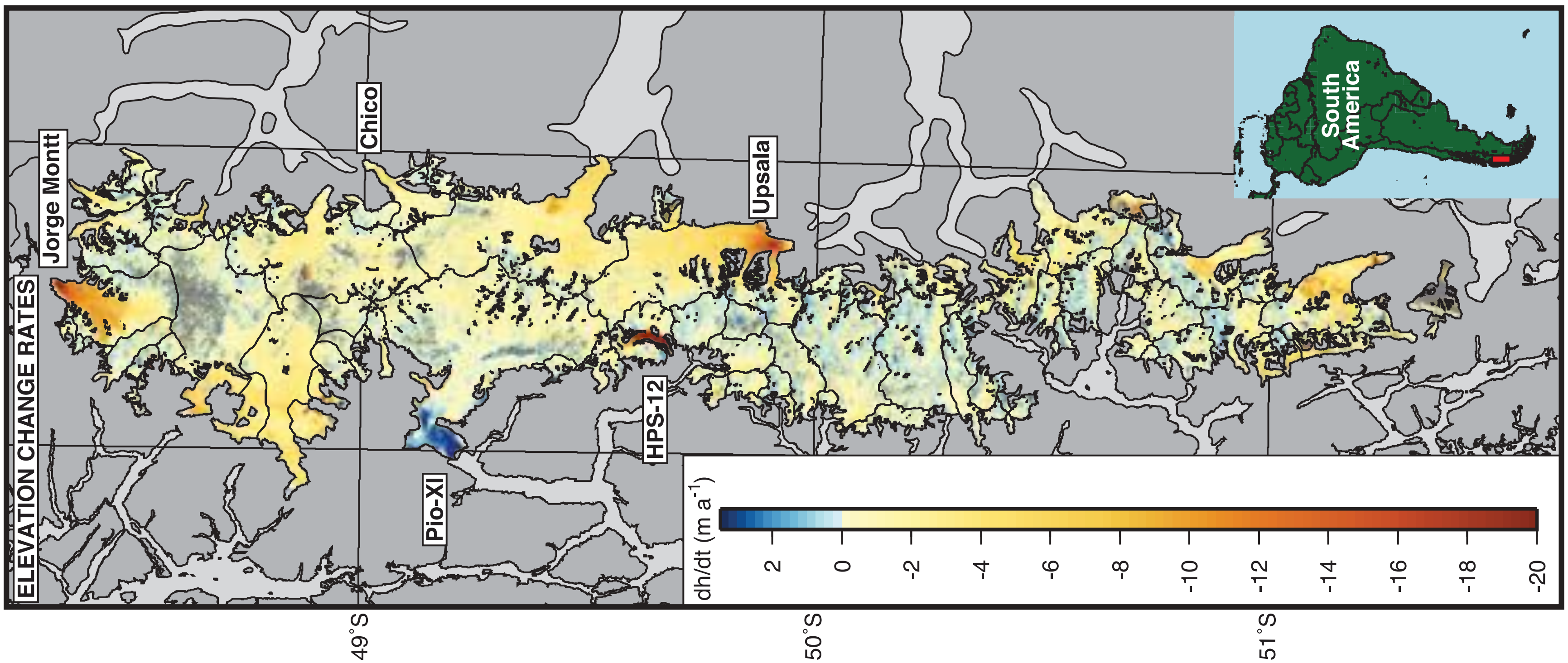


GPS Vertical responds to surface water load

California drought of 2014

ICE LOSS FROM THE SOUTHERN PATAGONIAN ICE FIELD, SOUTH AMERICA, BETWEEN 2000 AND 2012

Willis, Melkonian Pritchard, & Rivera 2012.



Optical & radar techniques (Aster & SRTM) to constrain ice height change - Southern Patagonian Ice Field

Substantially higher than late 20th Century rates, but in good agreement with GRACE

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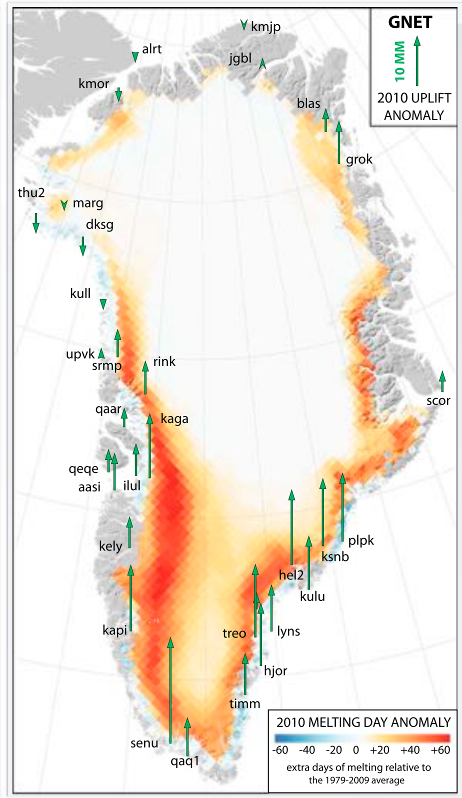
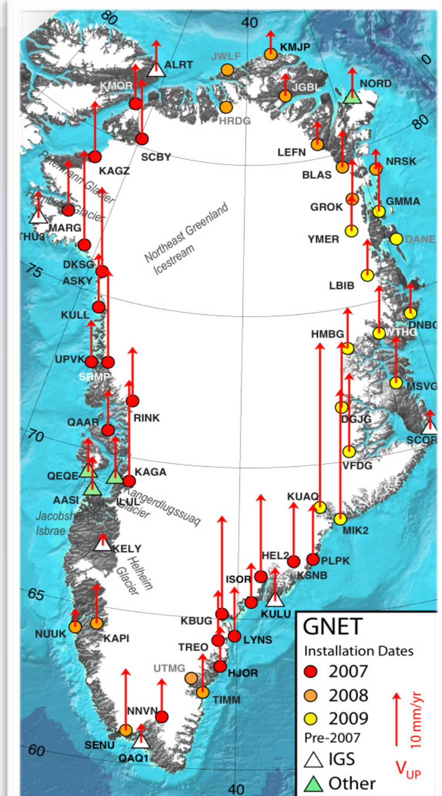
GREENLAND UPLIFT RECORDS ICE MASS CHANGE

Bevis, Wahr, Khan, Madsen, Brown, Willis, Kendrick, Knudsen, Box, van Dam, J. Caccamise II, Johns, Nylen, Abbott, White, Miner, Forsberg, Zhou, Wang, Wilson, Bromwich, & Francis, 2012

- Uplift shows an annual oscillation imposed on sustained trend
- Reflects elastic response to seasonal ice & air mass change on sustained contemporary ice loss
- 2010 — largest *annual melting day anomaly* on record
- Large pulse of uplift over six months
- Meltwater lakes and rivers crack the ice, lubricating the base of the ice sheet



2010 vertical uplift anomaly



annual vertical velocity

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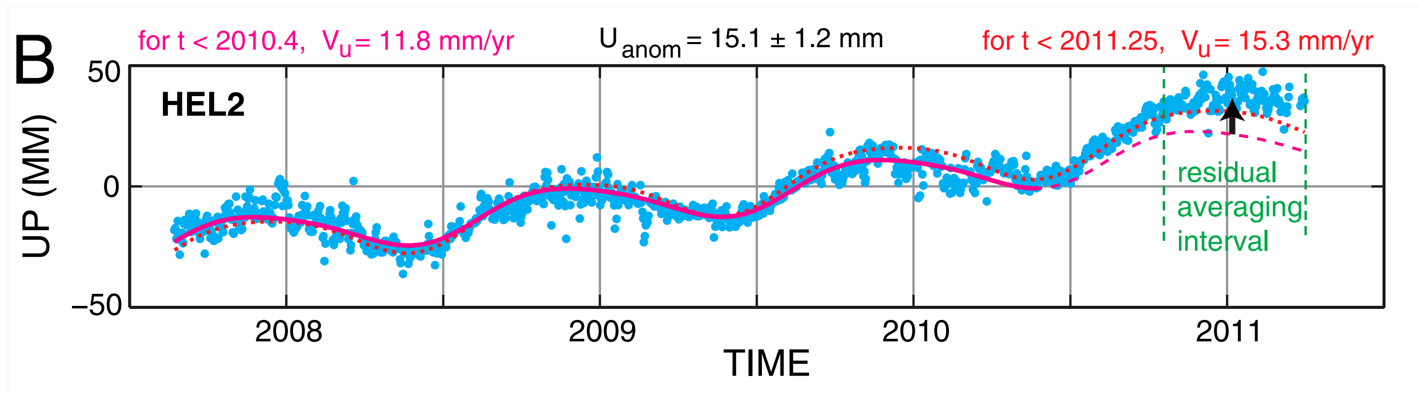

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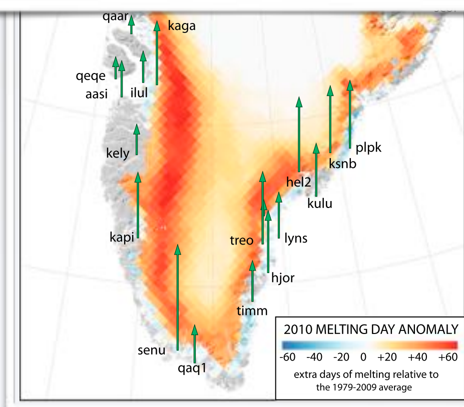

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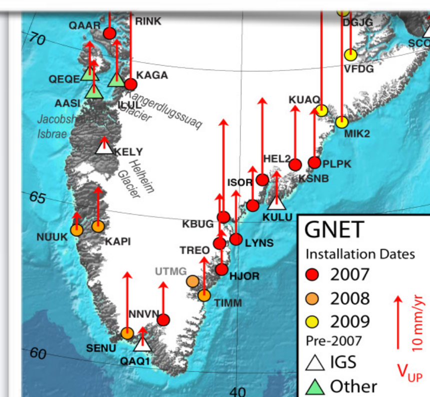


annual vertical velocity

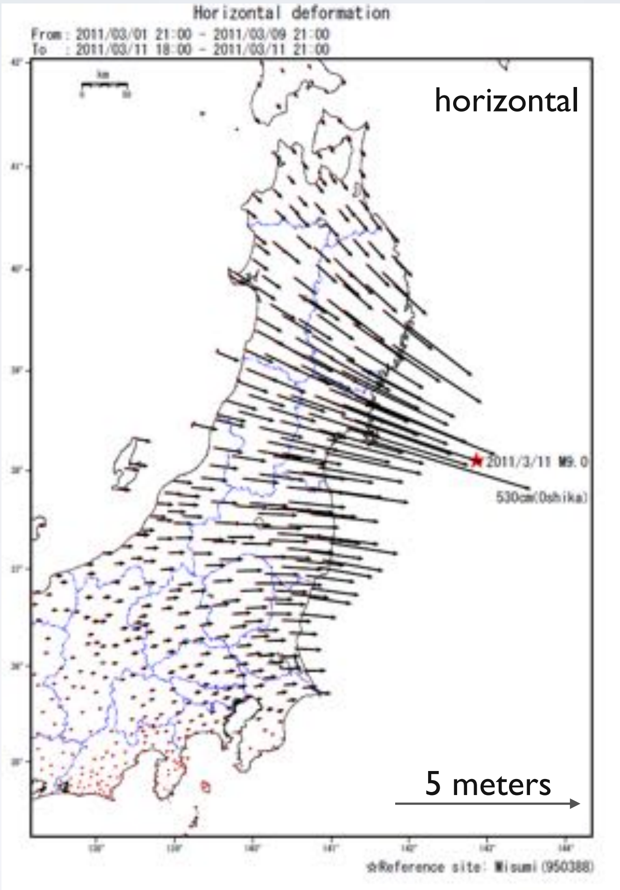
TOHOKU RECONSTRUCTION — HAMPERED BY THE LOSS OF THE REFERENCE FRAME

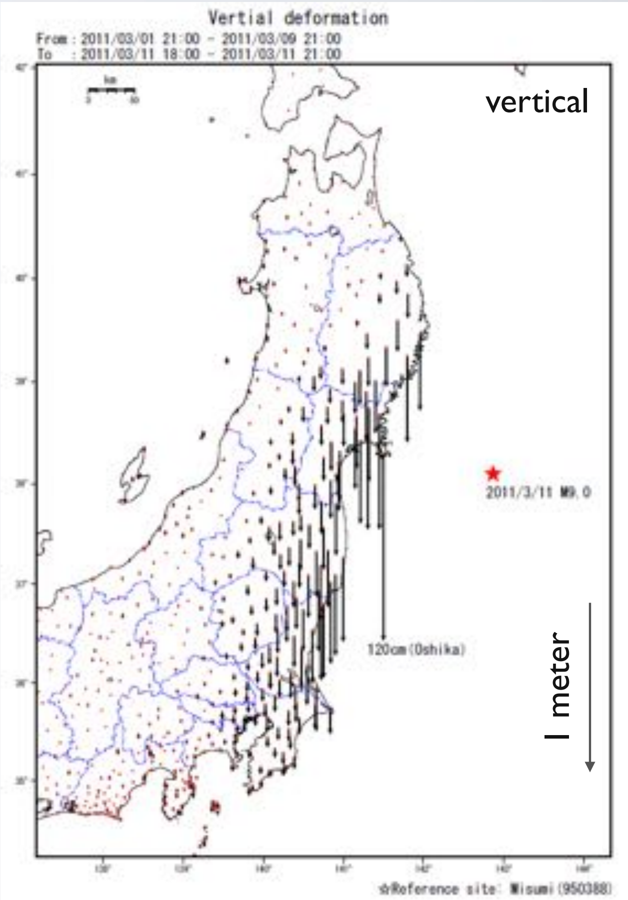
Co-seismic offsets up to 5.3 m horizontal, 1.2 m vertical March 11, 2011

Loss of the reference frame; GPS location services discontinued - announced March 14, 2011

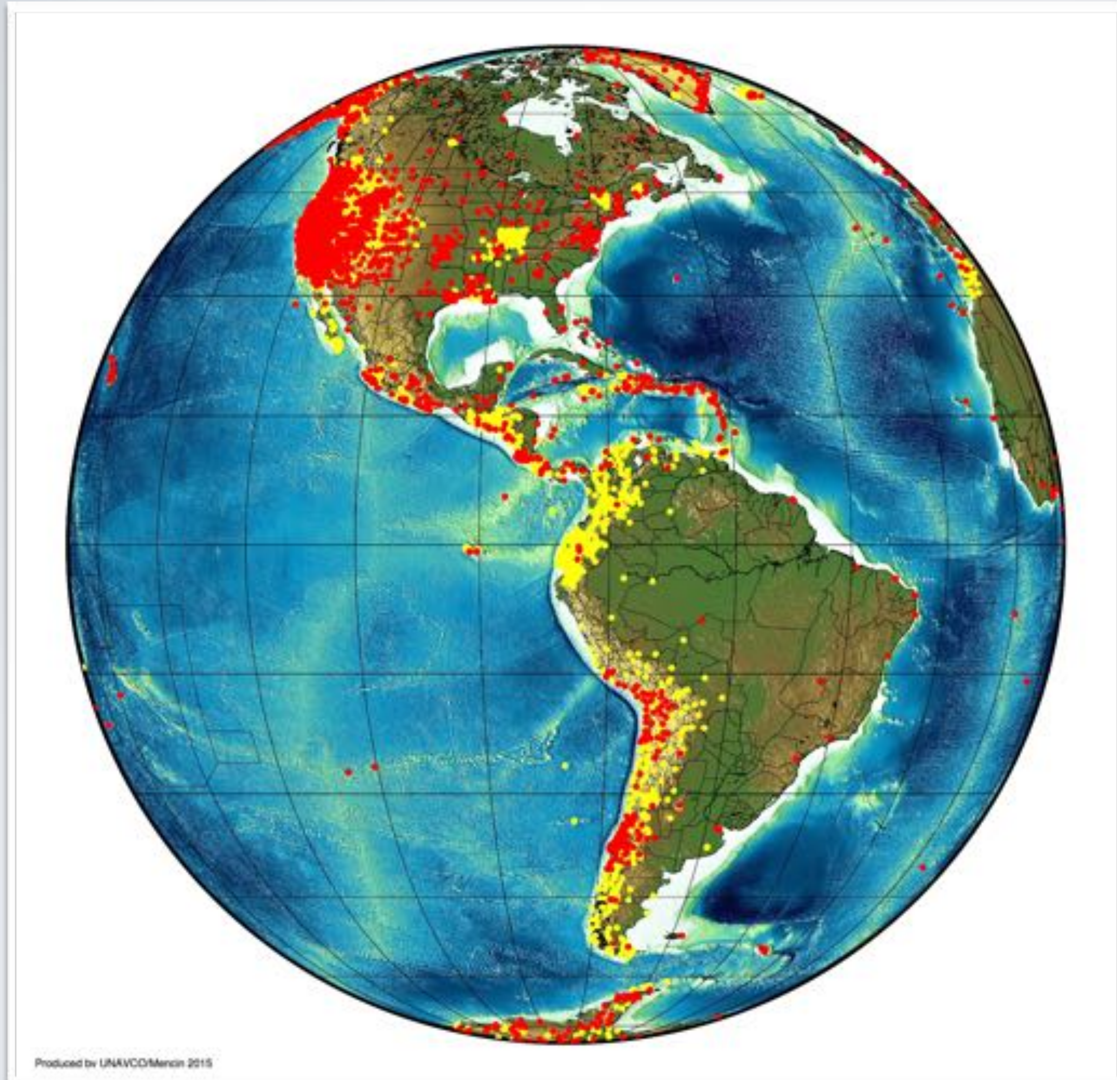
Recovery of reference frame relies on International GNSS Service (with UNAVCO support)

Corrected reference frame established May 31, 2011





Hiyama, Yamagiwa, Kawahara, Iwata, Fukuzaki, Shouji, Sato, Yutsudo, Sasaki, Shigematsu, Yamao, Inukai, Ohtaki, Kokado, Kurihara, Kimura, Tsutumi, Yahagi, Furuya, Kageyama, Kawamto, Yamaguchi, Tsuji, and Matsumura, 2012



NETWORK OF GEODETIC NETWORKS FOR THE AMERICAS

DATAWORKS FOR GNSS

- Software and hardware solutions for managing GNSS data flow and metadata
- Developed under COCONet and TLALOCNet by UNAVCO for international collaboration
- Regional Data Centers established in Barbados, Colombia, Mexico, and Nicaragua
- Training conducted in December 2014

GSAC - GNSS Seamless Archive Centers

- For data discovery, access and interaction, initially among three U.S. NASA archives
- Based on shared metadata
- The holdings of all archives are visible from each
- Implementation now extended to key European partners

Network of Geodetic Networks for the Americas -

- UNAVCO seeks additional key partners for western hemisphere-scale implementation
- Collaborative development and dissemination of tools for data management, archiving and distribution