GSI Introduction

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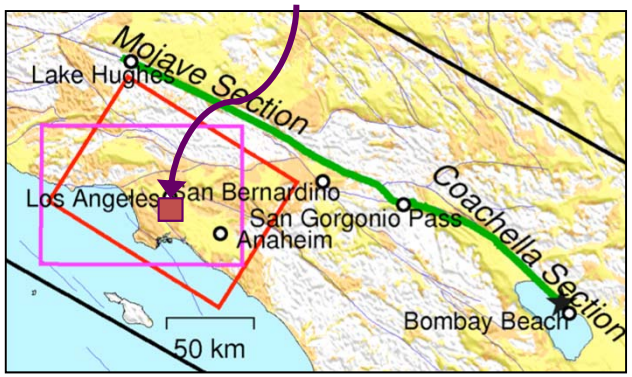
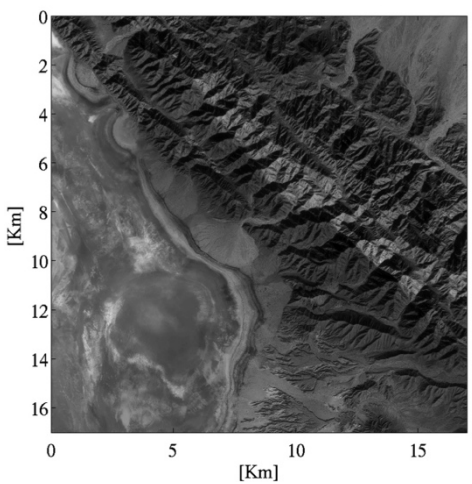
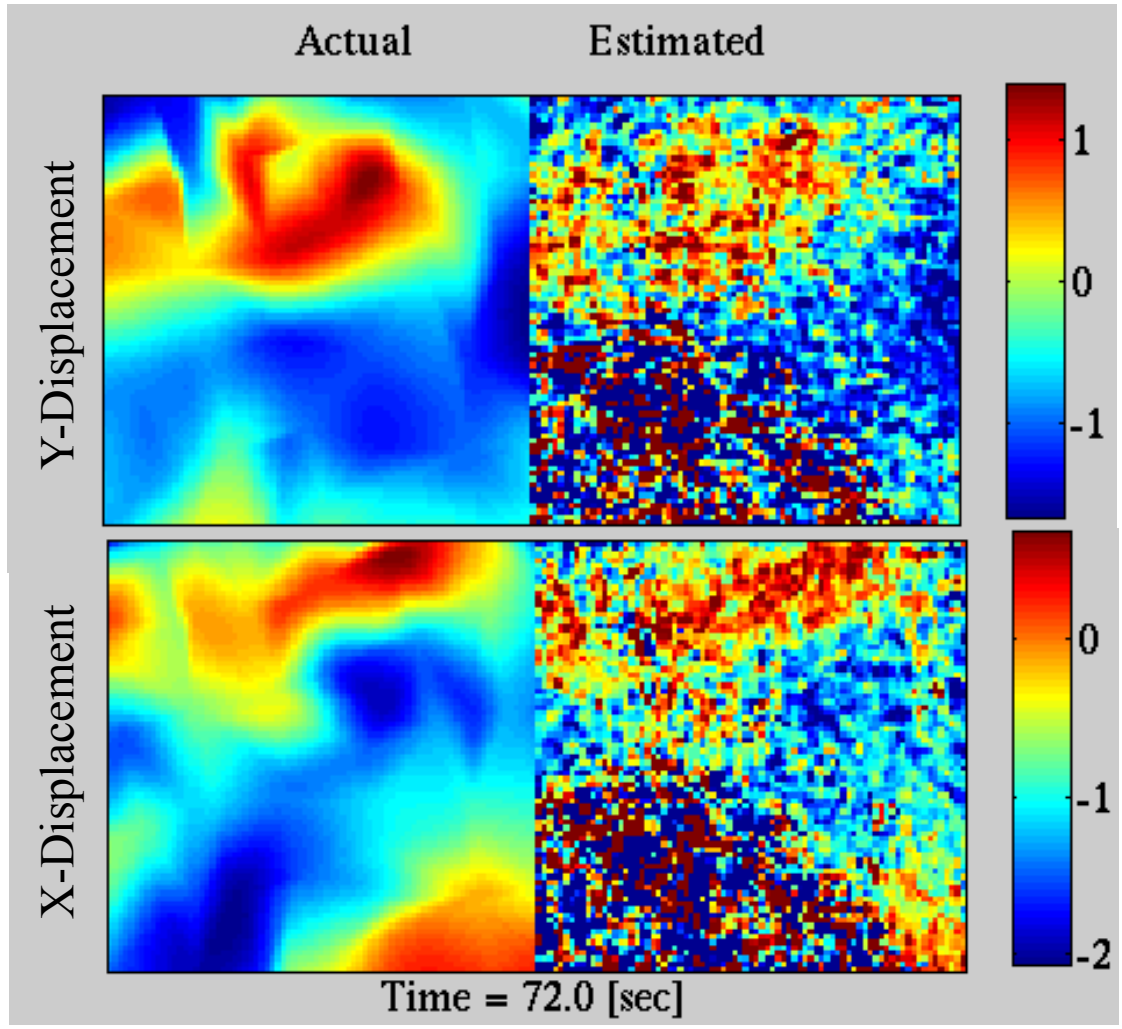
GSI: Shakeout Measurement Simulation

Area simulated



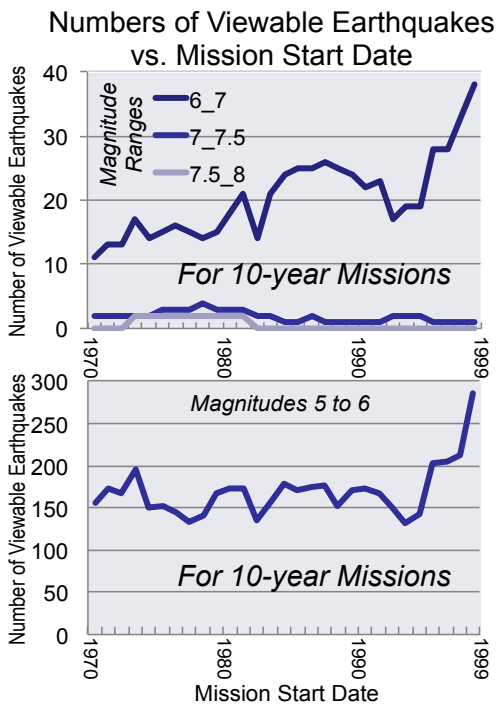
Unshifted Frame

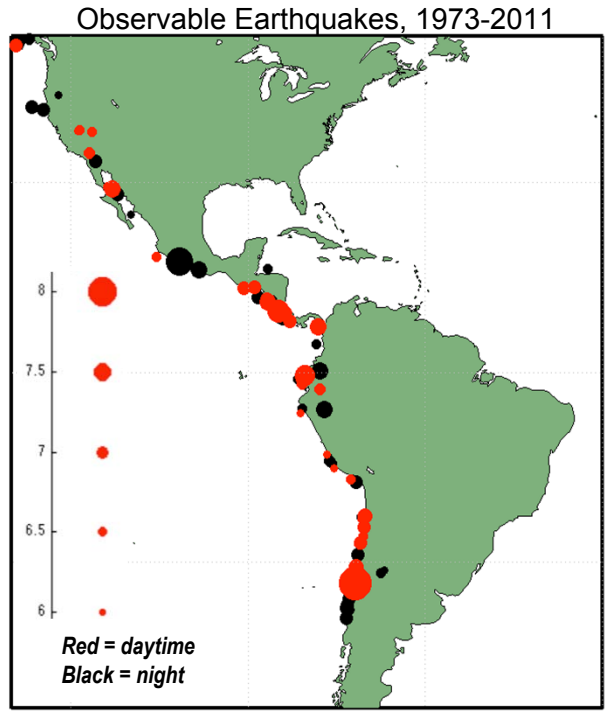




- **Shakeout Sim: a M_v = 7.8 quake as seen by a 3.6m GSI**

GSI: Observational Strategy





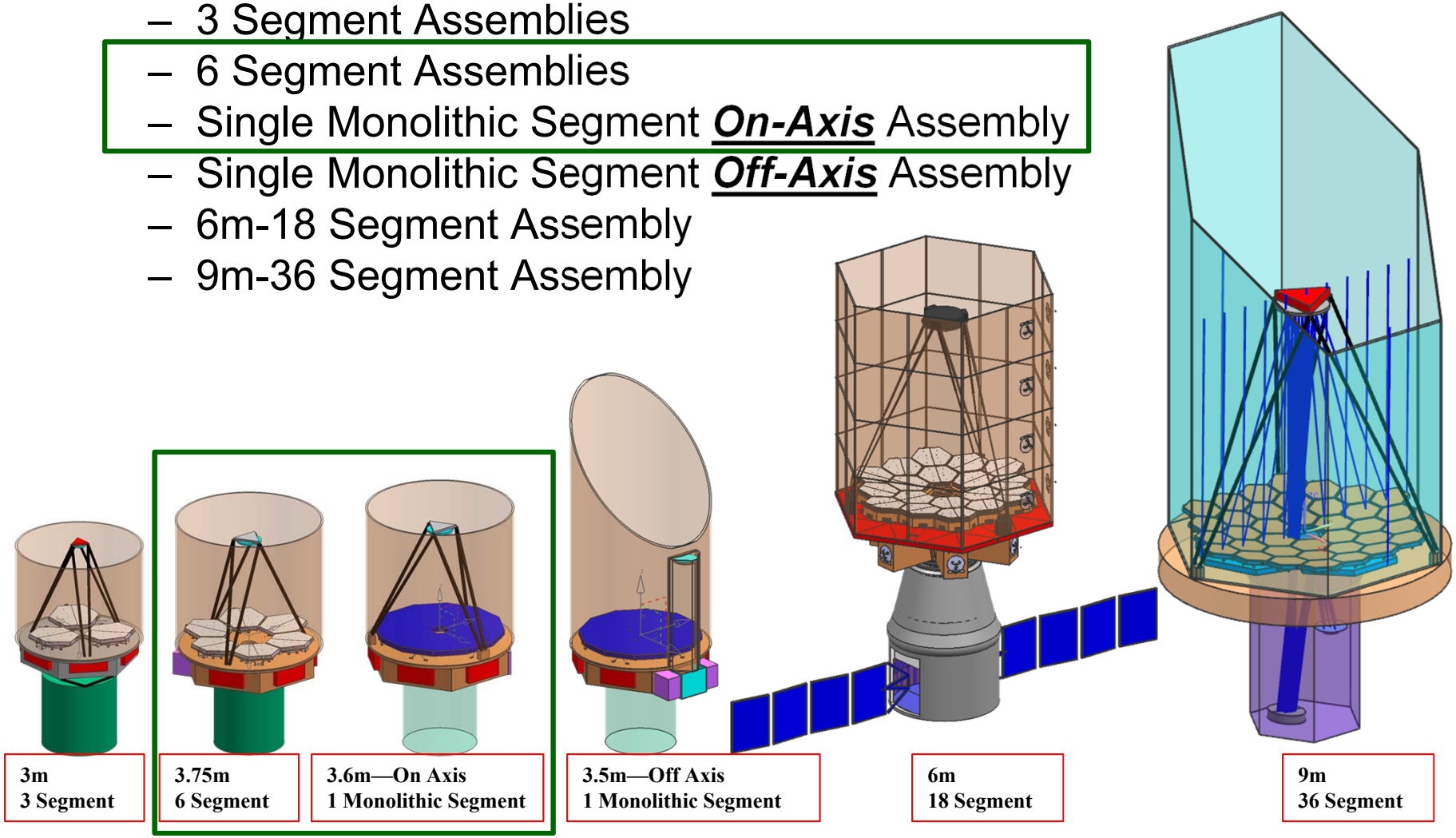
- **Observable EQs are those for which:**
  - $M_v \geq 6$
  - Rupture overlaps FoV
  - Depth $D \leq 40$ km
- **A 10-year GSI mission would see on average:**
  - 22 EQ with $M_v > 6$
  - 2 EQ with $M_v > 7$

Data from USGS/NEIC PDE earthquake catalog.

- **When a "trigger" earthquake (EQ) with $M_v \geq 5$ occurs, as detected by ground seismometry, slew the GSI to point at its epicenter**
- **Continuously observe the epicenter for up to 2 weeks, recording data into a ring buffer, and downlink it when EQ is observed**
- **When a different EQ with $M_v \geq 5$ occurs, switch to point at it**
- **Stationed in GEO over the Pacific coast of the Americas, GSI would be in position to observe 1 to 4 $M_v > 6$ earthquakes per year**

GSI : Candidate Configurations

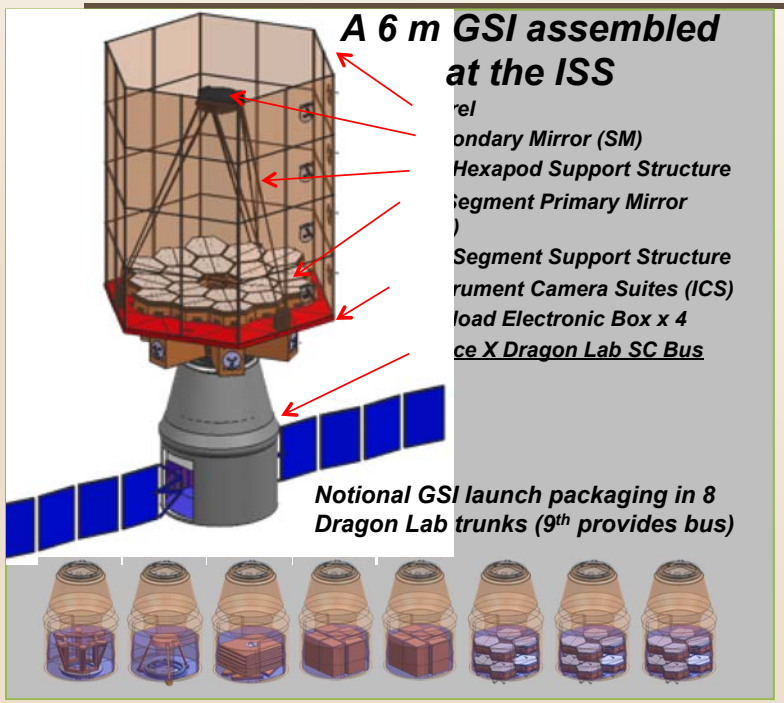
- **System Configuration Standard Views:**
  - 3 Segment Assemblies
  - 6 Segment Assemblies
  - Single Monolithic Segment ***On-Axis*** Assembly
  - Single Monolithic Segment ***Off-Axis*** Assembly
  - 6m-18 Segment Assembly
  - 9m-36 Segment Assembly



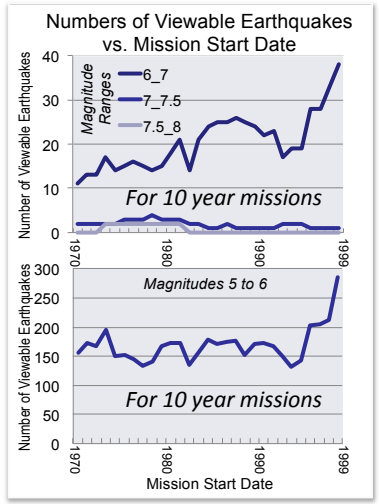
Requirements

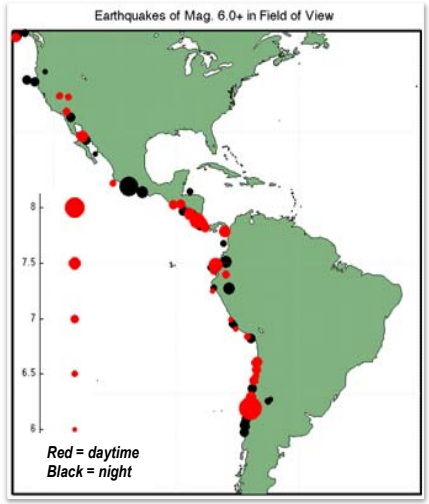
- Geosynchronous Orbit (GEO)
- Field of View (FoV) up to 300km by 150km
- <2 cm/s resolution on 200 m grid
- 1-2 Hz frame rate
- Pointing
  - 3.75 Segmented
    - Control = 180 arcsec, consistent with drift
    - Stability
      - Drift = 9.2 mas/sec
      - Jitter = 4.8 mas over 0.5 sec interval
  - 3.6m Monolithic
    - Control = 180 arcsec, consistent with drift
    - Stability
      - Drift = 9.6 mas/sec
      - Jitter = 4.6 mas over 0.5 sec interval

GEO Seismic Imager

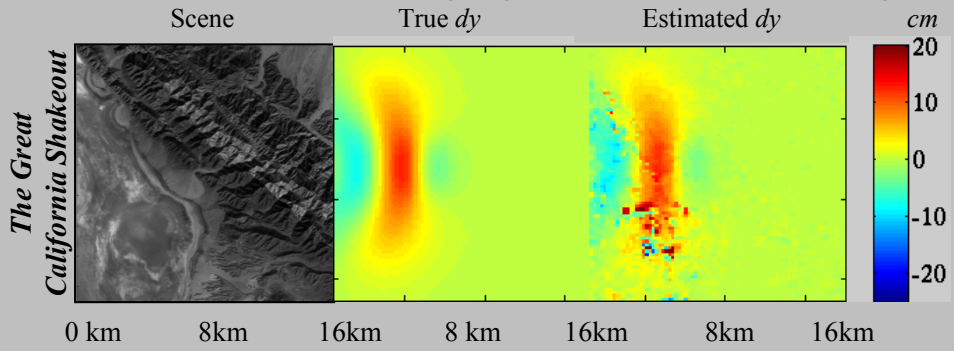


- An ISS-assembled 6m telescope for imaging large earthquakes
- Telescope is pointed in response to events detected on the ground
- Stationed in GEO over the Pacific coast of the Americas, GSI would be in position to observe 1 to 4 $M_v > 6$ earthquakes per year
- GSI data would revolutionize earthquake seismology





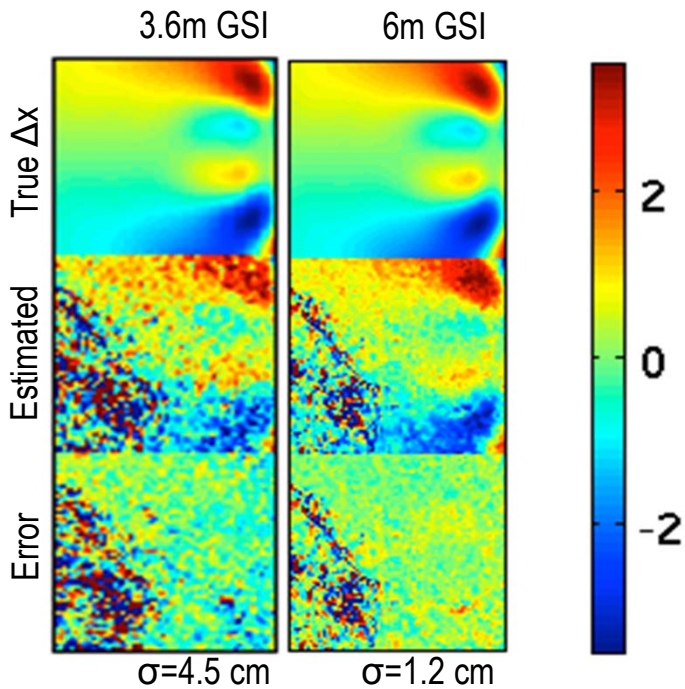
Simulation of GSI Imaging and Data Processing



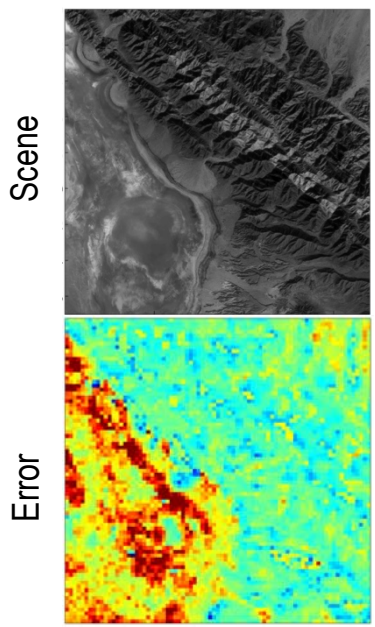
- *Image frame rate is 2Hz, with 20 min of rolling data storage*
- *Resolution as good as 1 cm on a 200m grid, over a field of view up to 300 km by 300 km*
- *Surface deformation movies reveal rupture propagation, enabling correlation of ground motion to subsurface geology*
- *GSI data could ultimately lead to effective warning capabilities and to improved public management of earthquake risk*

GSI: Performance vs. Aperture

Displacement Estimation



Estimation Error Driven by Scene Content



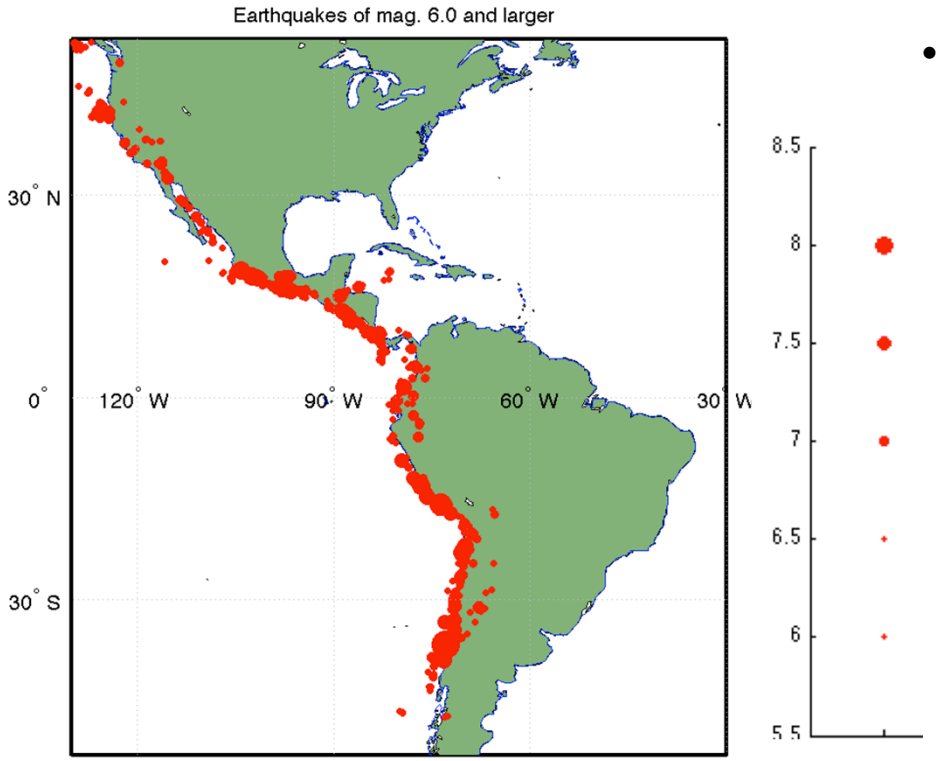
- **Weighting image by quality improves estimation error**
  - Estimation error for 3.6m GAI improves from 5 cm to 1 cm in key regions
- **Estimation can also be improved by correlating over larger areas, at the expense of spatial resolution**

- **Comparing 3.6 and 6m aperture shift estimation error:**
  - 6m GSI has small shift estimation error in all parts of the scene
  - 3.6m GSI has small error in high contrast parts of the scene, but worse performance in flatter regions (using normal approach)
  - Performance can be improved by better algorithms…

GSI: Value Proposition

- **A 3.6m GSI covering 300 km by 300 km square Field of View (FoV)**
  - Optical flow processing produces displacement measurements on a grid of width 50 m to 250 m
    - Balance grid width vs. accuracy; will be optimized for particular observations
  - Accuracy as good as 1 cm frame-to-frame
    - Depends on image content, aperture, atmospheric conditions, and time of day
  - FoV can be moved anywhere along the Pacific coast of the Americas
- **To produce similar data would require a grid of ground-based seismometers at the same spacing (50 to 250 m)**
  - Ground instruments are capable of better accuracy and true 3-D, but…
  - To cover one single 300 km square field would require 1,400,000 to 36,000,000 tightly synchronized separate instruments
  - To cover all areas of interest on the Pacific Coast of the Americas would require many times more instruments than that
- **A GSI would provide data of unprecedented density and area coverage, at a cost likely to be far lower than could be obtained with ground-based seismometer grids**

Pacific Coast Earthquakes



- **Total number of earthquakes (EQ) along the Pacific coast of the Americas with $M_v \geq 5$ (1973-2011):**
  - Total of 5173 EQ with hypocentral depth shallower than 100 km
  - 3770 had a hypocentral depth of 40 kilometers or less, for observable EQ
  - 4642 were of magnitude less than 6.0, 331 were between 6.0 and 6.5, 128 were between 6.5 and 7.0, 66 were between 7.0 and 8.0, and 6 were 8.0 or larger
  - 2630 occurred during the day

- **We studied the USGS/NEIC PDE earthquake catalog:**
  - EQs along the western coast of the Americas between 50° N and 50° S
  - EQs occurring between January 2nd, 1973 and June 28th, 2011
  - EQ magnitude of 5 and larger

FPA Sampling

FPA Sampling for 3 Candidate GSI Designs

Aperture	**3.6m**	**3.75m**	**6m**
FPA width	**72,000 pix**	**75,000 pix**	**120,000 pix**
Pixel count	**5.2 Gpix**	**5.6 Gpix**	**14.4 Gpix**

- **Focal Plane Array (FPA)**
  - 5 um pixels, f/12 focal ratio
  - Pixel count varies with aperture to preserve near-Nyquist sampling of 4.1 pixels/PSF at 700 um wavelength
  - Pixel GSD varies from 2.5 to 4.167m
  - 1-2 Hz frame rate
- **300 km square Field of View (FoV), viewed from GEO**
  - Optical flow processing correlates 100-500 m overlapping cells, with 1 cm best-case error
  - Compare to a grid of 36e6-1.4e6 ground-based “seismometers” at same spacing
    - GSI grid can be “transported” anywhere on the Pacific coast of the Americas in ~10 minutes

Estimated Cost

- For the 3.6m or 3.7m, 10 year mission, estimated to be less than $2B by JPL TeamX.
- Project to be proposed to next NASA decadal survey.