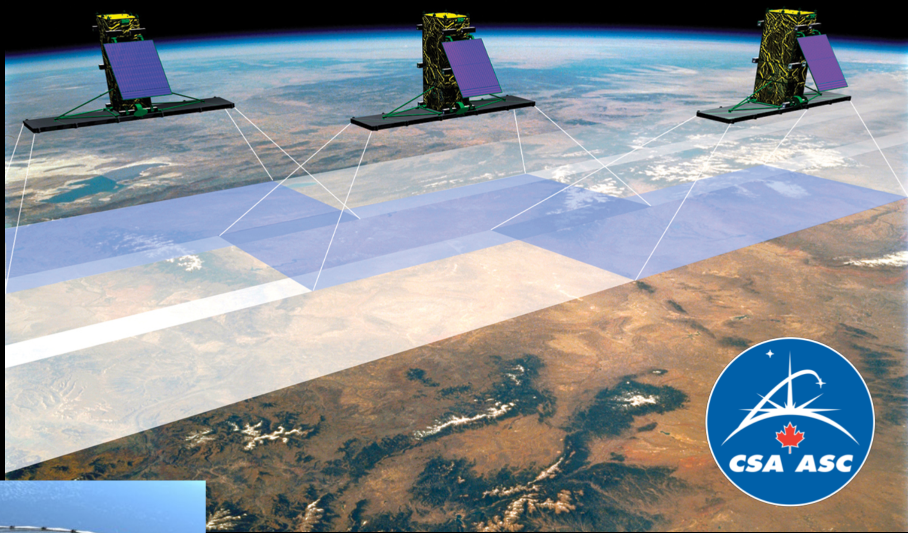
Satellite Radar Remote Sensing for Science, Monitoring and Disaster Response

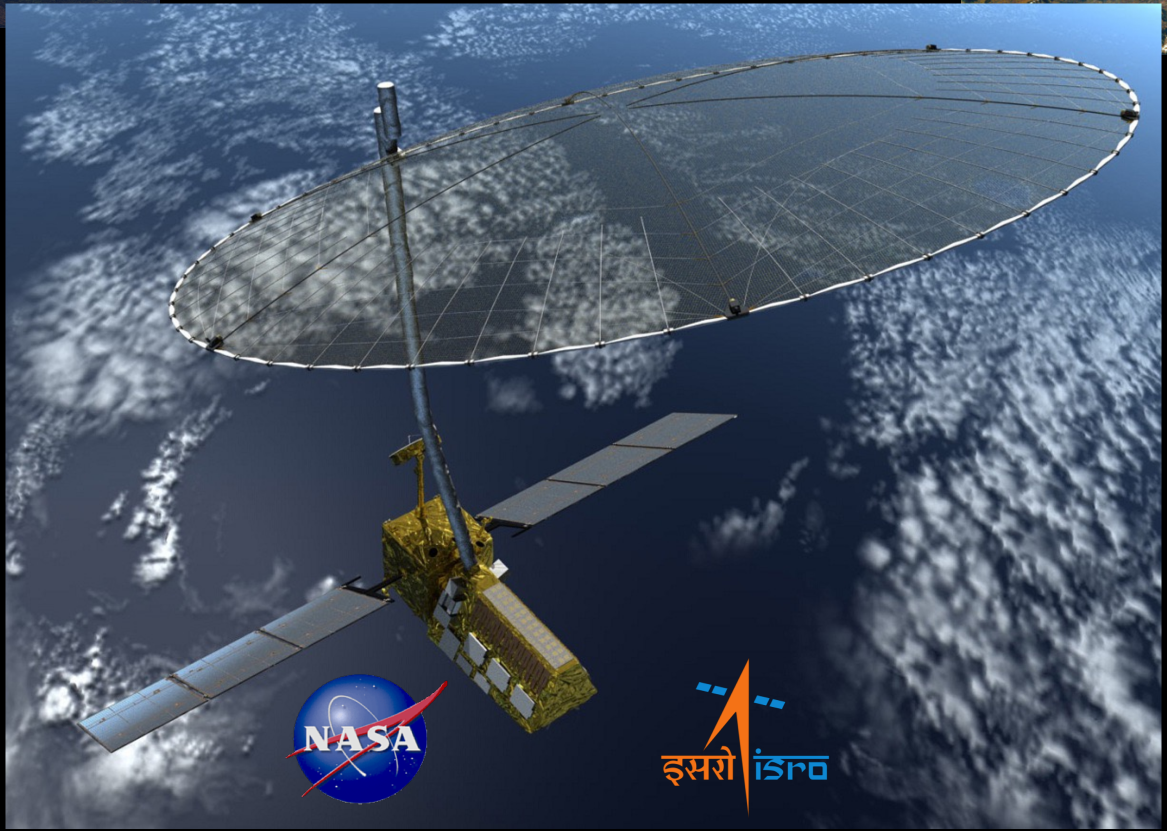
CMS273 – Ollie, Tobias, Zach & Mark

California Institute of Technology & Jet Propulsion Laboratory

Photo Courtesy: Time Magazine

Present/Future



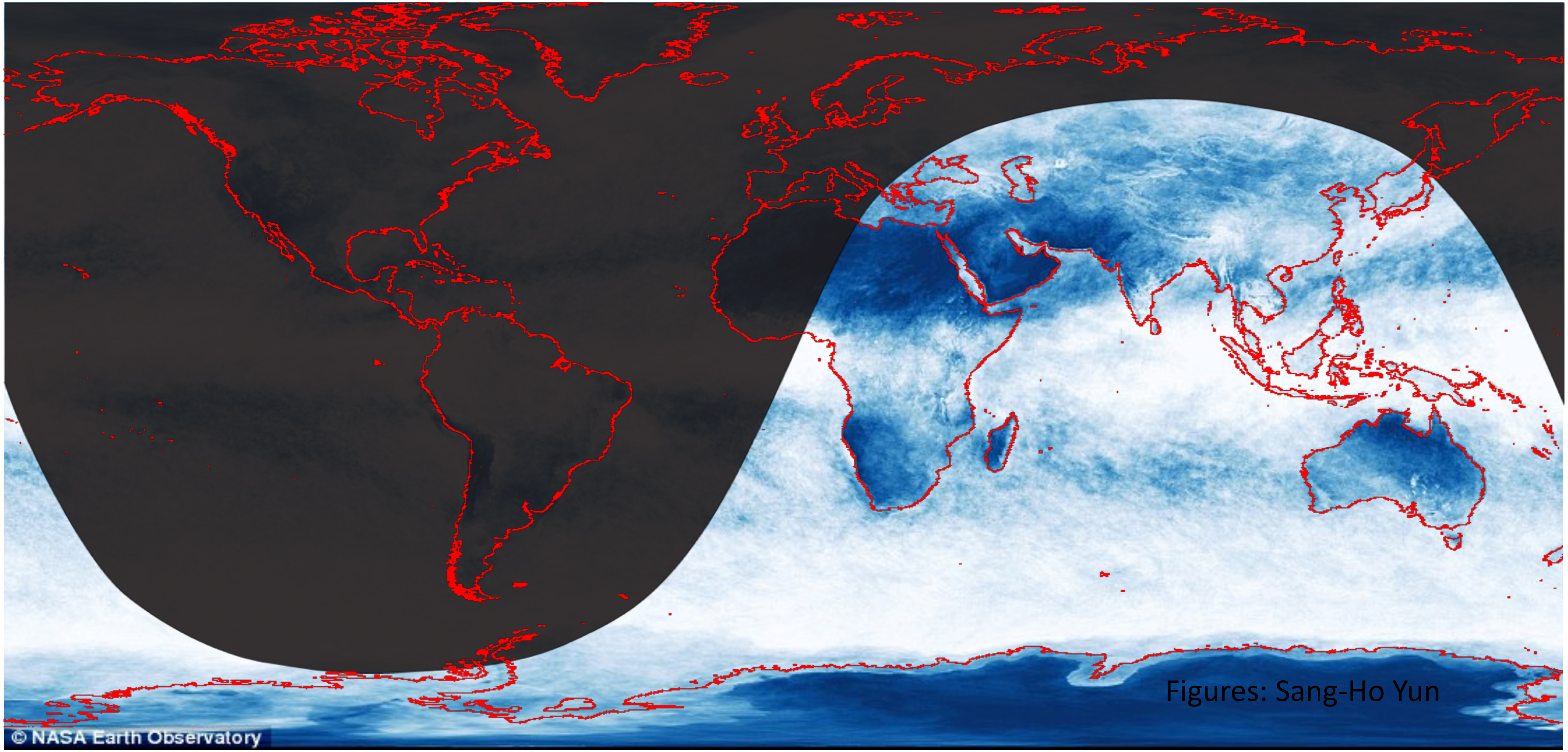


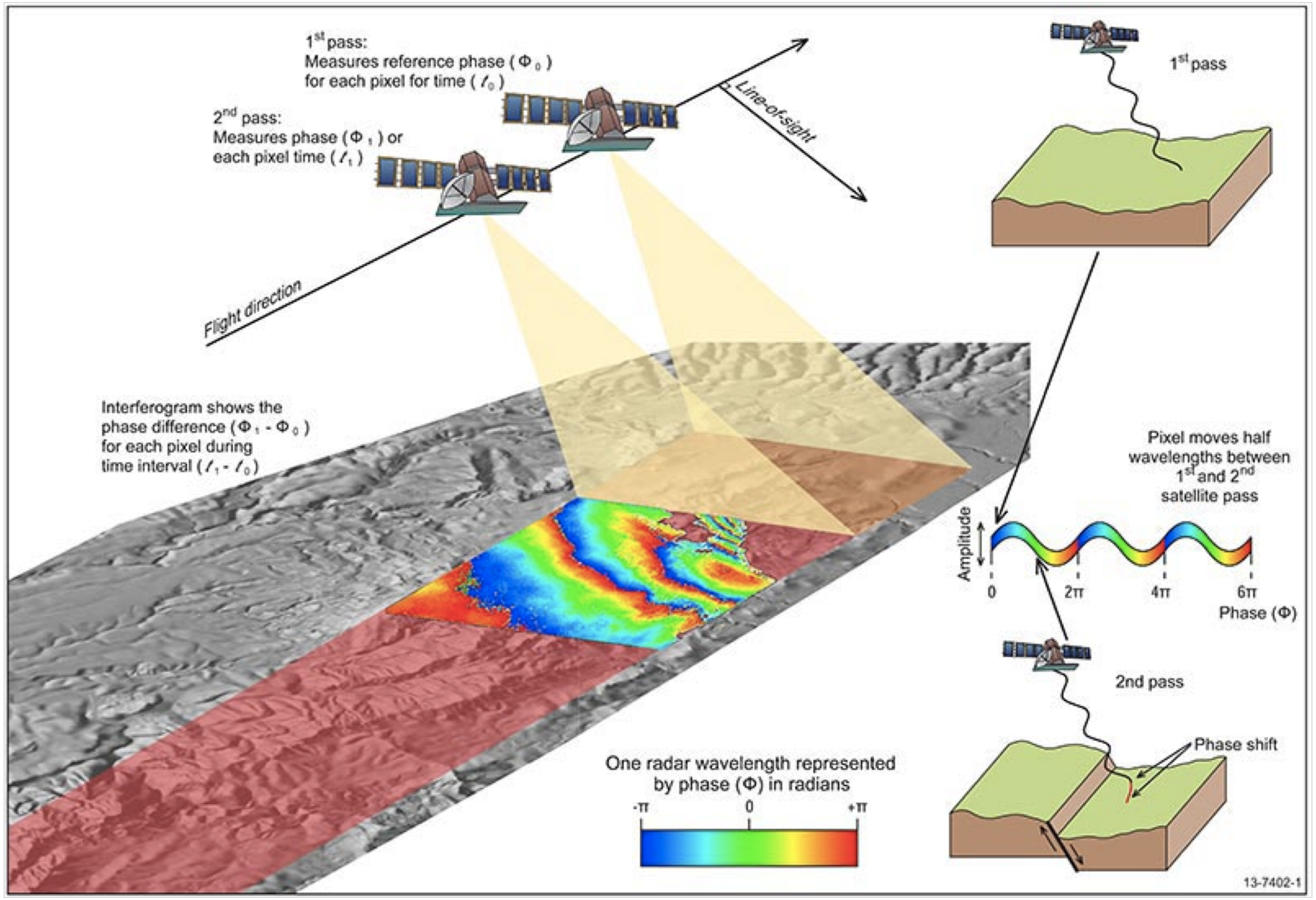
35 Tbits/day

Quasi-daily imaging

Disaster Response Using Radar Remote Sensing

Radar "sees" through clouds and at night – unlike optical data

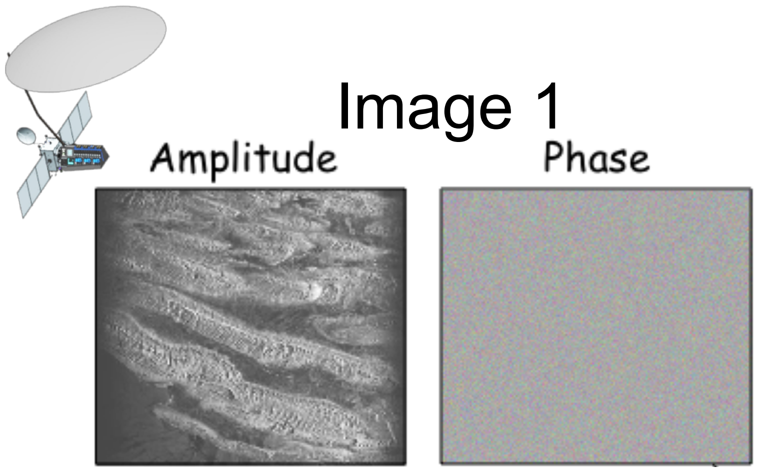



1st pass:
Measures reference phase (Φ 0)
for each pixel for time (t 0)
2nd pass:
Measures phase (Φ 1) or
each pixel time (t 1)
Line-of-sight
Flight direction
Interferogram shows the
phase difference (Φ 1 - Φ 0)
for each pixel during
time interval (t 1 - t 0)
1st pass
Pixel moves half
wavelengths between
1st and 2nd
satellite pass
Amplitude
0
2π
4π
6π
Phase (Φ)
2nd pass
Phase shift
One radar wavelength represented
by phase (Φ) in radians
-π
0
+π
13-7402-1

Measuring ground movement using satellite radar images

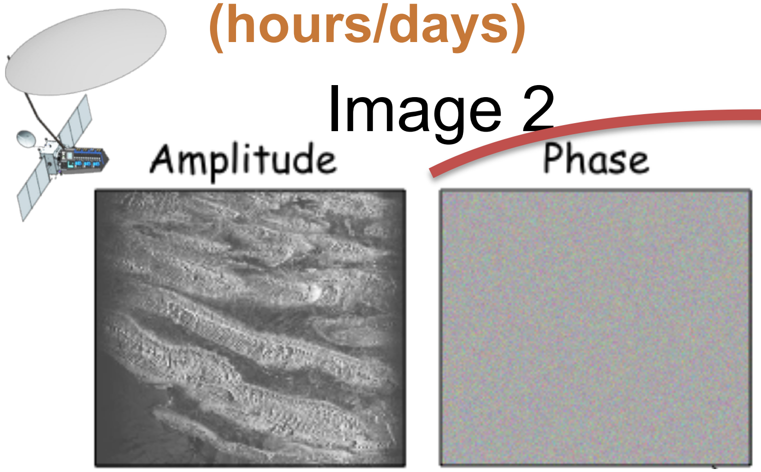
Interferometric Synthetic Aperture Radar (InSAR)

Image 1



Wait a for some time (hours/days)

Image 2



Images:
100's km in extent with meter scale resolution

Satellite orbits
Signal & Image processing
Tides
Atmospheric models
Cartography/GIS
…

Maps of coherent (net) movement
Maps of incoherent (scramble) movement

Background

- The international constellation of radar satellites allows us to provide rapid high-resolution synoptic assessments of devastation following natural disasters (e.g., earthquakes, floods, fires, etc.).

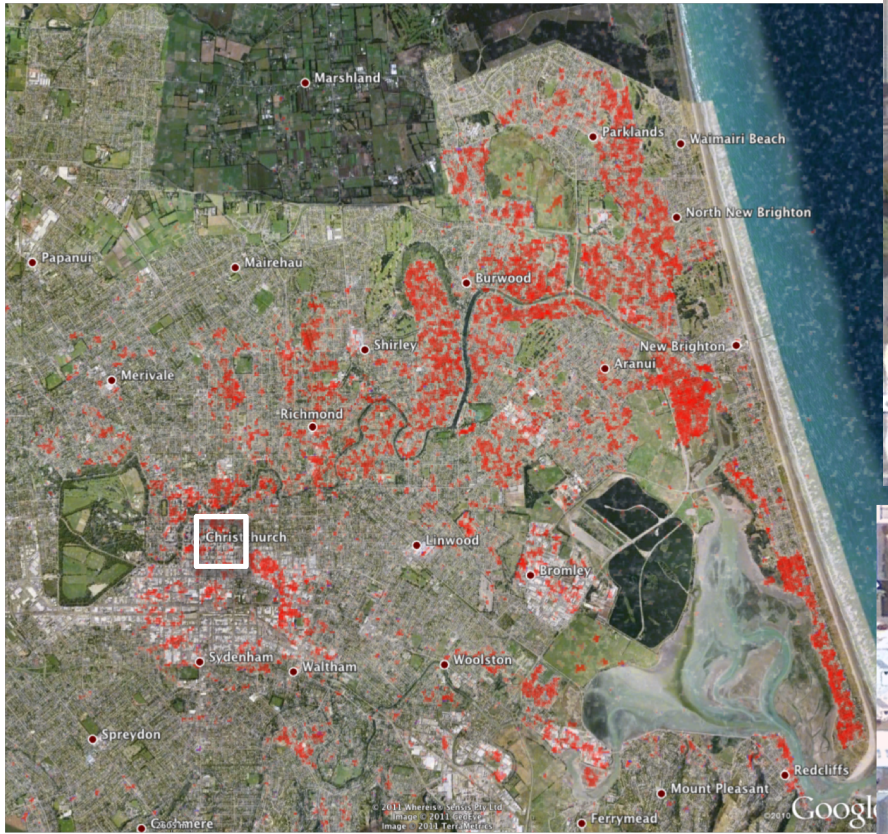
- Each radar image *spans O(100km)* in each dimension with *O(m) pixel resolution*. Each pixel has both an amplitude and a phase. These images are known as single look complex images (SLCs), where the single-look means it is full resolution has not been spatially averaged.

- The amplitude for each pixel is the amount of radar energy scattered back to the satellite and the phase (0:2pi) represents the distance between the ground and the satellite measured in units of the radar wavelength, but with no sensitivity to the integer number of wavelengths, just the last fractional part.

- Interferometric synthetic aperture radar (InSAR) which relies on interferometric differences between two images. Consecutive co-registered images can provide synoptic maps of ground movement that occurred in the time spanned by the two images. However, if something disrupts the ground (e.g., a building failure) in the same time span, then the measurement for the relevant pixel is randomized. We refer to this as *interferometric decorrelation*.

Assessing Devastation From Space:
Mw 6.3 Christchurch, NZ earthquake February 21st, 2011

In Hours to Days – Radar Remote Sensing



The Damage Proxy Map indicates significant centimeter scale change due to subsidence, inundation, or structure collapse allowing early assessment of the scale of damage. [1]

Figures: Sang-Ho Yun

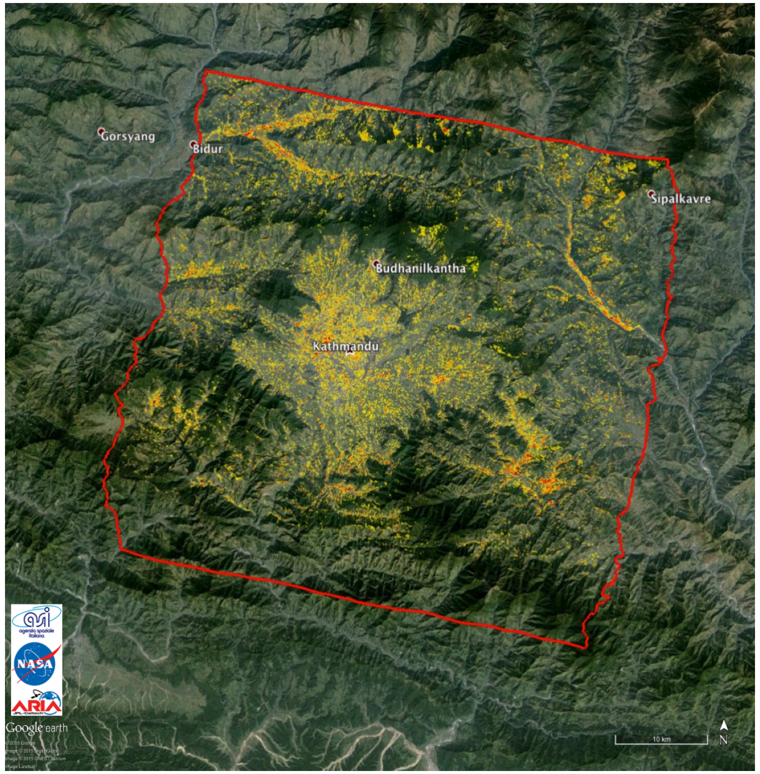
ssment

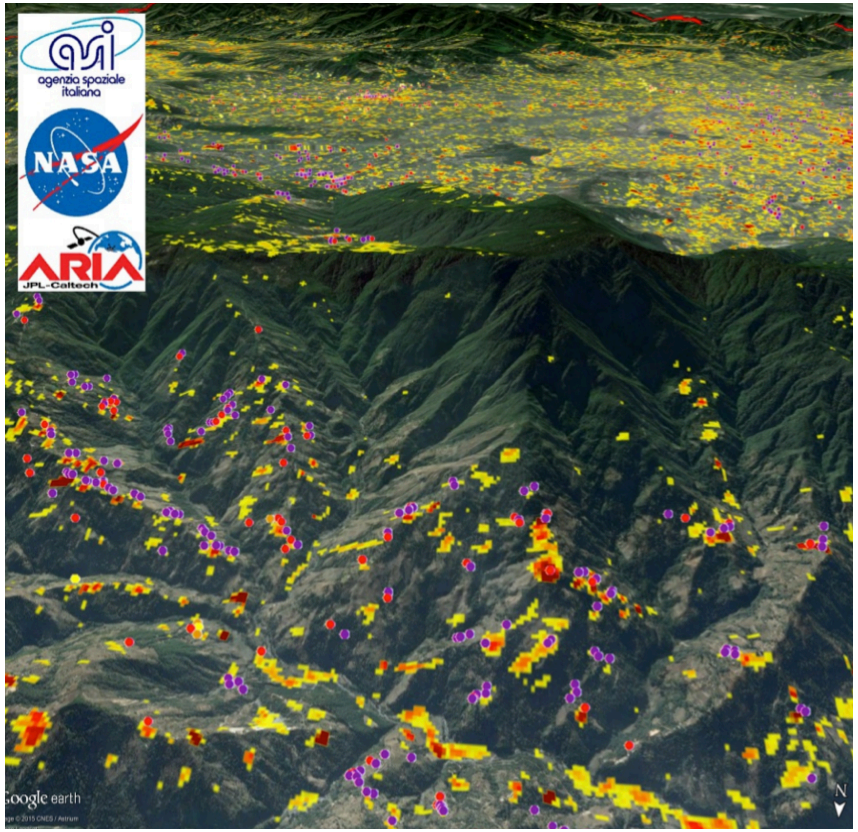
Christchurch Cathedral

Canterbury TV Building

d rebuilding will be
man-hours of effort to
ere built on. [2]

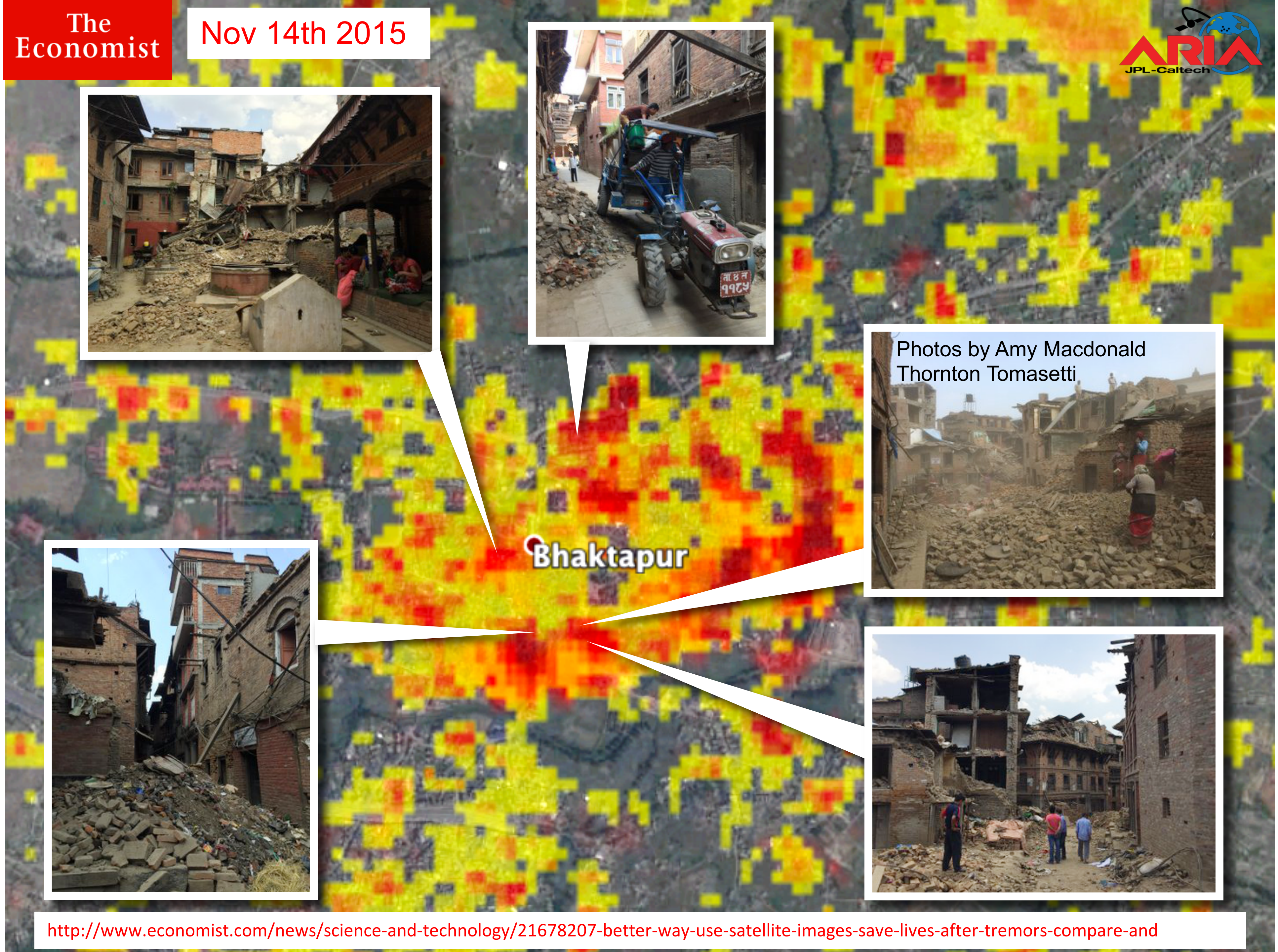
DPM For The Mw7.8 Nepal Earthquake





Figures: Sang-Ho Yun

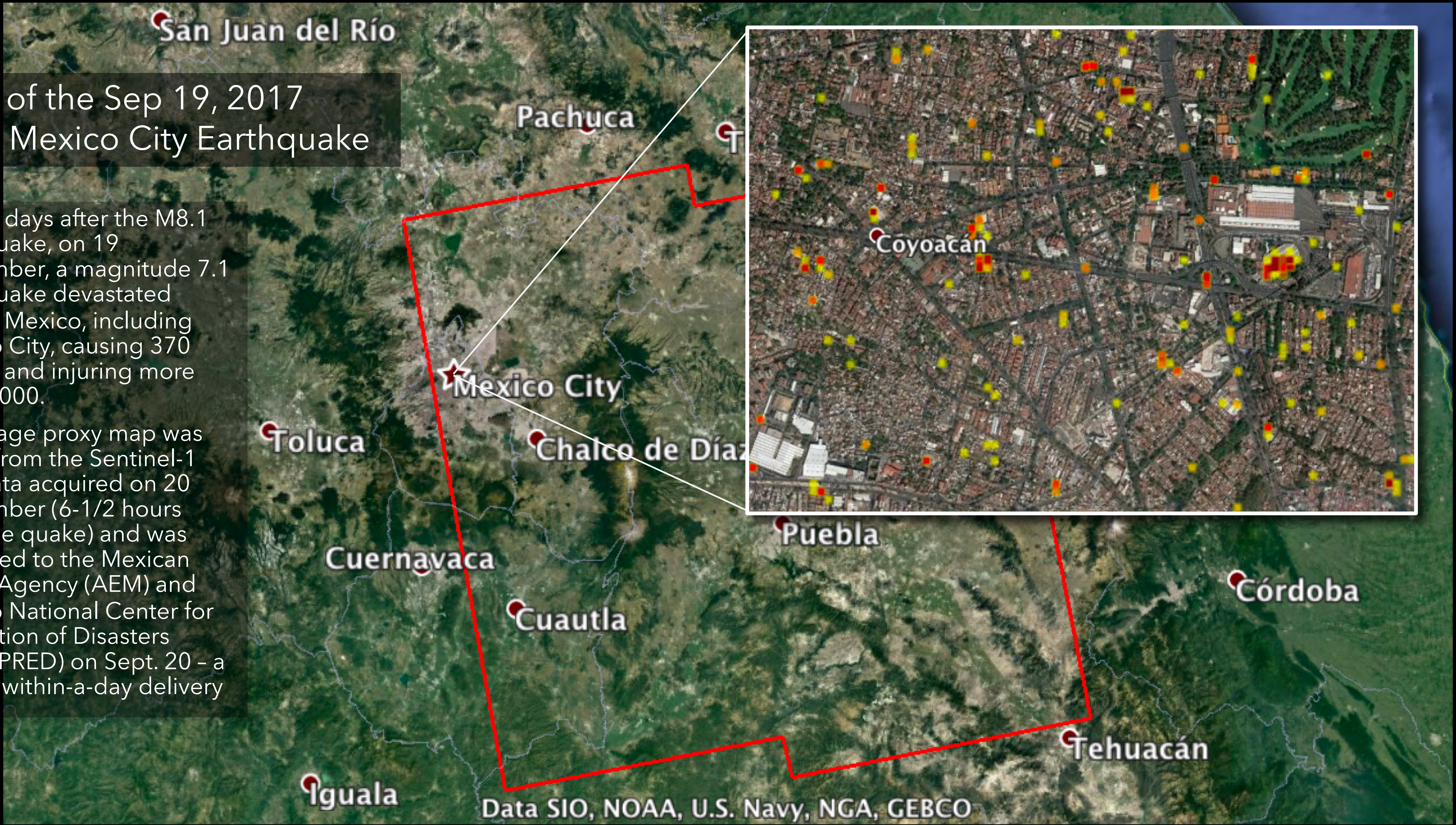
Relationship to shaking and topographic effects?


The Economist
Nov 14th 2015
ARIA
JPL-Caltech
Photos by Amy Macdonald
Thornton Tomasetti
Bhaktapur
http://www.economist.com/news/science-and-technology/21678207-better-way-use-satellite-images-save-lives-after-tremors-compare-and

DPM of the Sep 19, 2017 M7.1 Mexico City Earthquake

Twelve days after the M8.1 earthquake, on 19 September, a magnitude 7.1 earthquake devastated central Mexico, including Mexico City, causing 370 deaths and injuring more than 6,000.

A damage proxy map was made from the Sentinel-1 SAR data acquired on 20 September (6-1/2 hours after the quake) and was delivered to the Mexican Space Agency (AEM) and Mexico National Center for Prevention of Disasters (CENAPRED) on Sept. 20 – a record within-a-day delivery

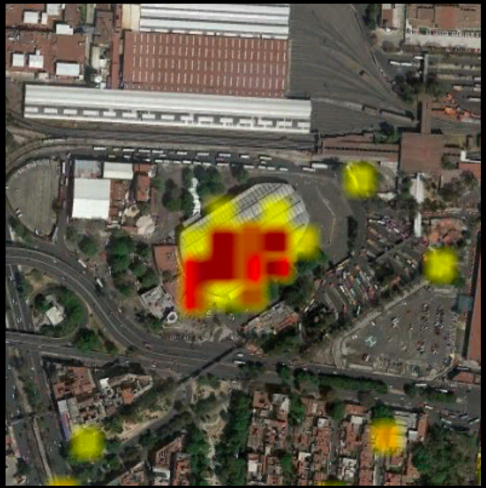


https://www.nasa.gov/feature/jpl/nasa-produced-damage-maps-may-aid-mexico-quake-response

Soriana Tasqueña

Source: Google

Source: www.adn40.mx



DPM

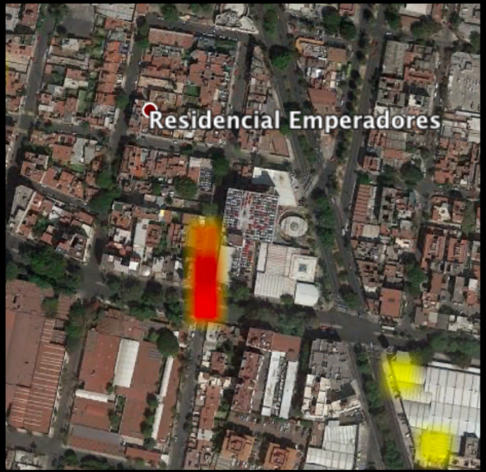
Before

After

Residential Building on Emiliano Zapata

Source: Google

Courtesy: New York Times



DPM

Before

After

Current State of Affairs

- Identification of anomalous pixel behavior can be used to guide emergency officials responding to disasters. We refer to these estimates as damage proxy maps (DPMs).

- Currently, we provide key information used by FEMA and many other organizations in the U.S. and abroad for rapid response and situational awareness.

- *However*, we currently exploit only a *two pairs of images* and do not take advantage of time series of hundreds of images that are now routinely available. *Thresholds for identification are manually set and no confidence metrics are available.* (How sure are we that what we have flagged as damaged is not actually natural change in the surface properties of the earth?).

- *Furthermore*, our current approaches *sacrifice maximum spatial resolution* as they are based on local ensembles.

The Challenge

- Starting from stacks of O(100) co-registered radar images, exploit all the *spatial and temporal* information available in the *complex* InSAR data and to *provide confidence intervals* on our estimates.

- Beyond DPM-style applications, these change detection problems arise in monitoring deforestation, desertification, as well as *damage distributed both in space and in time* (e.g., routine building demolition/construction or devastation in war zones).

- This effort naturally falls into the domain of *classification/clustering* combined with *anomaly detection*. *(ML/DL?)* We imagine both *supervised* and *unsupervised* approaches may be useful.

- Data volumes are large, visualization needs significant, algorithmic possibilities are multiple and, of course, eventual impact on society is profound.

As a brief background, you check out:

http://web.gps.caltech.edu/~simons/publications/pdfs/Yun_etal_2015.pdf

and the *Yun et al* references contained therein.

Building Block in Pasadena, California
Building demolition ≈ Building collapse

2007/10/23

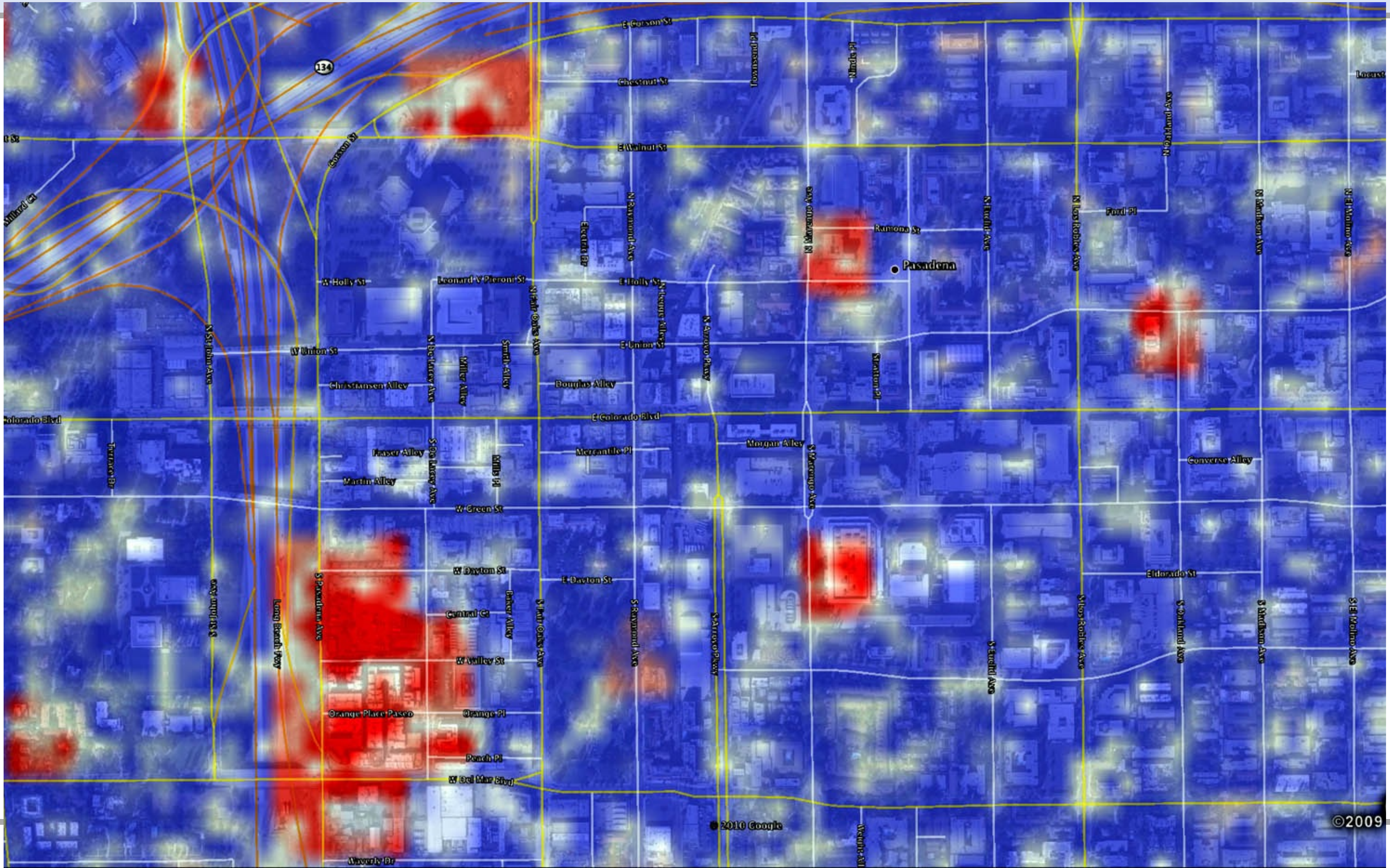
2009/11/15

Demolition: 2007/04/23 – 2008/01/22

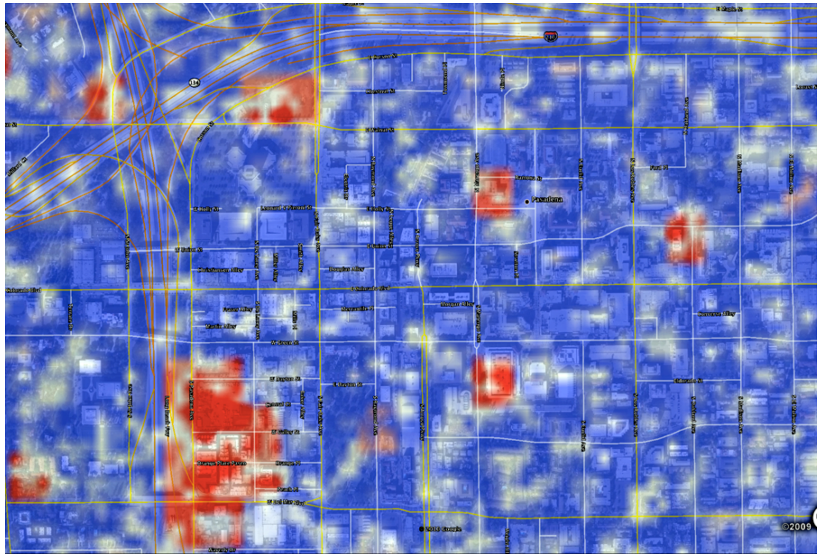
Google Earth
(Downtown Pasadena, CA on 2007/10/23)

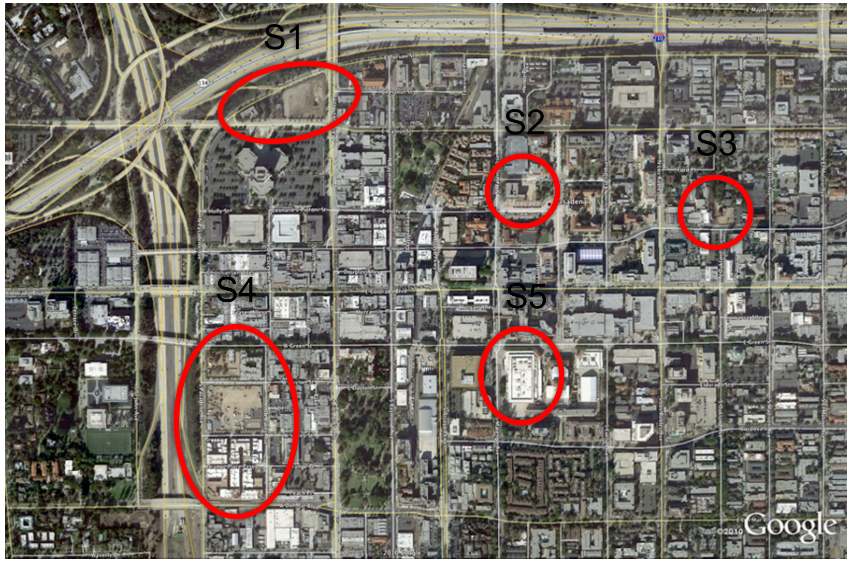
Google Earth
(Downtown Pasadena, CA on 2009/11/15)

Damage Proxy Map (Downtown Pasadena, CA)
2006/12/31 – 2007/02/15 – 2008/02/18



Combining Damage Proxy Map with GIS Reverse Geocoding





Geopy + Google geocoder:

S1: (34.150055, -118.151389) → 25 Walnut St., Pasadena, CA 91103

S2: (34.148033, -118.145444) → 235 E Holly St., Pasadena, CA 91101

S3: (34.147467, -118.139595) → 527 E Union St., Pasadena, CA 91101

S4: (34.141923, -118.153428) → 144 Valley St., Pasadena, CA 91105

S5: (34.143786, -118.145282) → 100-190 S Marengo Ave, Pasadena, CA 91101

Yun, S., Fielding, E., Simons., M., Webb, F., 2011. Damage Proxy Map from InSAR Coherence, U.S. Provisional Patent filed on June 20, 2011, Docket No. CIT-5901-P.