Damage Proxy Map of February 2011 M6.3 Christchurch Earthquake using InSAR Coherence

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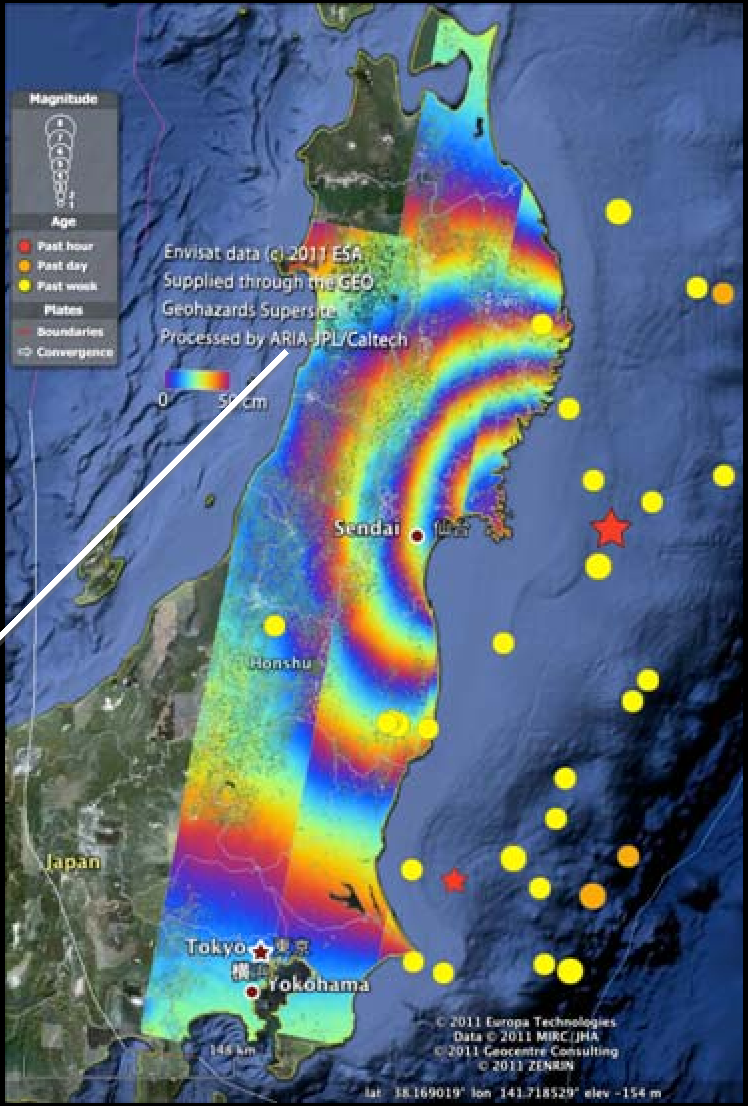
1. Jet Propulsion Laboratory
2. California Institute of Technology

ARIA (Advanced Rapid Imaging Analysis) project at JPL and Caltech

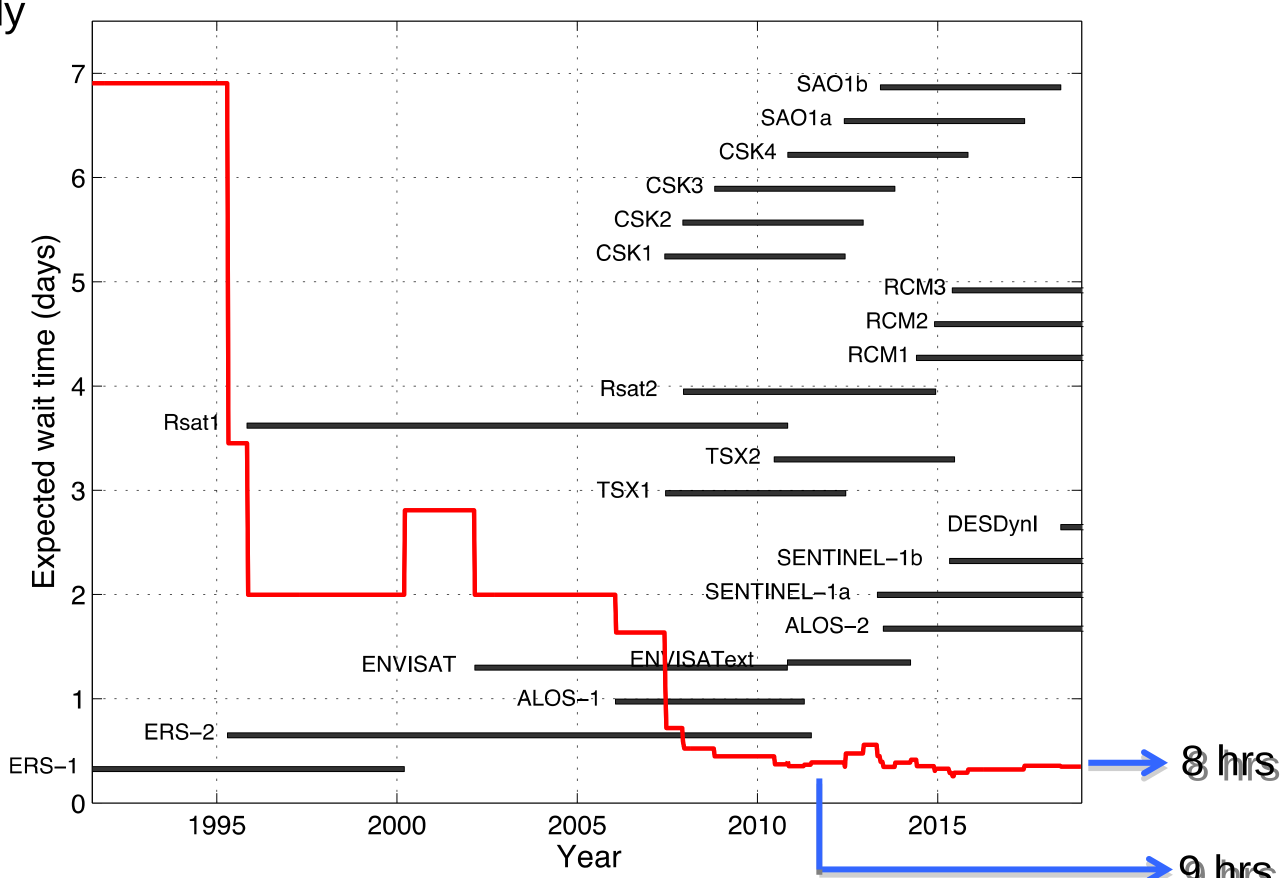


National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Expected Wait Time

for the first SAR satellite to visit after an event

- Ascending + Descending
- Right-looking only
- At 38° N



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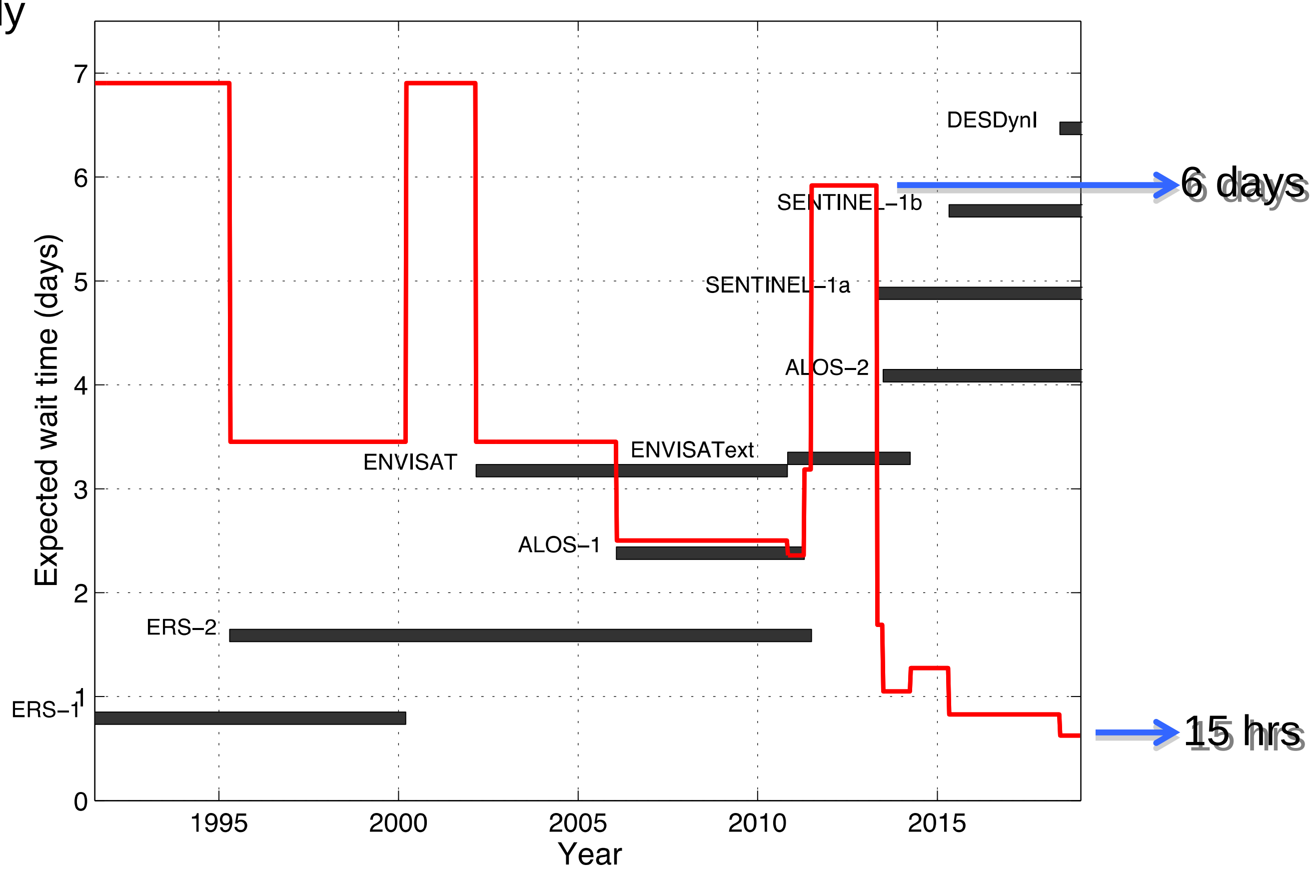


Damage Proxy Map of February 2011 M6.3 Christchurch Earthquake using InSAR Coherence

Outline

History and Concept

Algorithm Test: Pasadena Demolition (IEEE TGRS, in prep)

Application: Christchurch EQ

Conclusions and Future Work

History

Zebker and Villasenor, “Decorrelation in Interferometric Radar Echoes,” IEEE TGRS, 1992. → Cited by 764 papers

Zebker et al., “Analysis of active lava flows on Kilauea volcano, Hawaii, using SIR-C radar correlation measurements,” Geology, 1996.

Fielding et al., “Surface ruptures and building damage of the 2003 Bam, Iran, earthquake mapped by satellite synthetic aperture radar interferometric correlation,” JGR, 2005.

Hoffmann, “Mapping damage during the Bam (Iran) earthquake using interferometric coherence,” IJRS, 2007.

Controlling Parameters

Interferometric coherence

$$\gamma = \frac{|\langle c_1 c_2^* \rangle|}{\sqrt{\langle c_1 c_1^* \rangle \langle c_2 c_2^* \rangle}}, \quad 0 \leq \gamma \leq 1$$

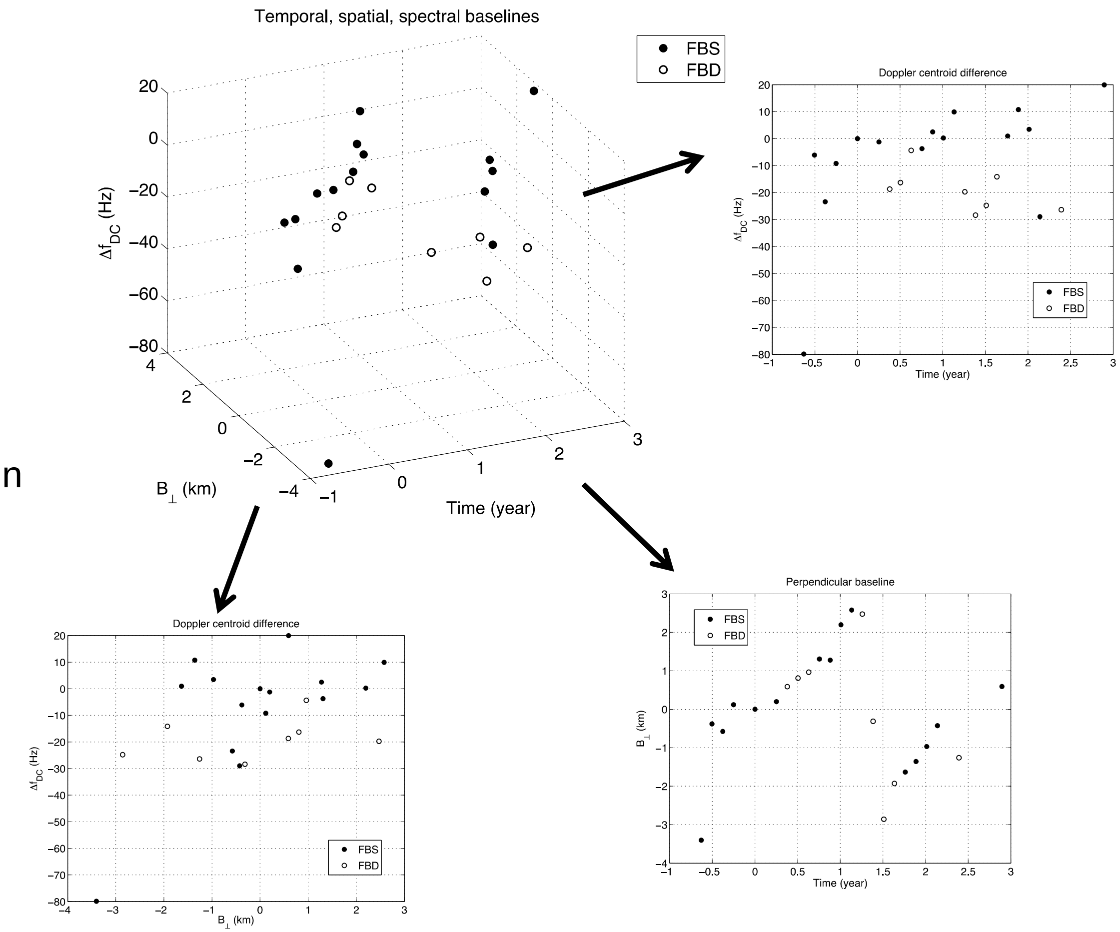
$$\gamma = \underline{\gamma_{B_p}\,\gamma_{B_t}\,\gamma_{B_f}}\,\gamma_V\,\gamma_K\,\gamma_P$$

baselines

volume scattering (γ_V)

thermal noise (γ_K)

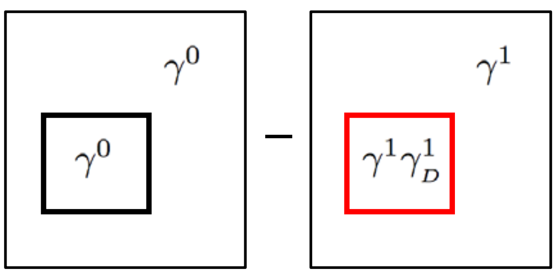
processing (γ_P)



Concept: Damage Decorrelation

Damage coherence: γ_D

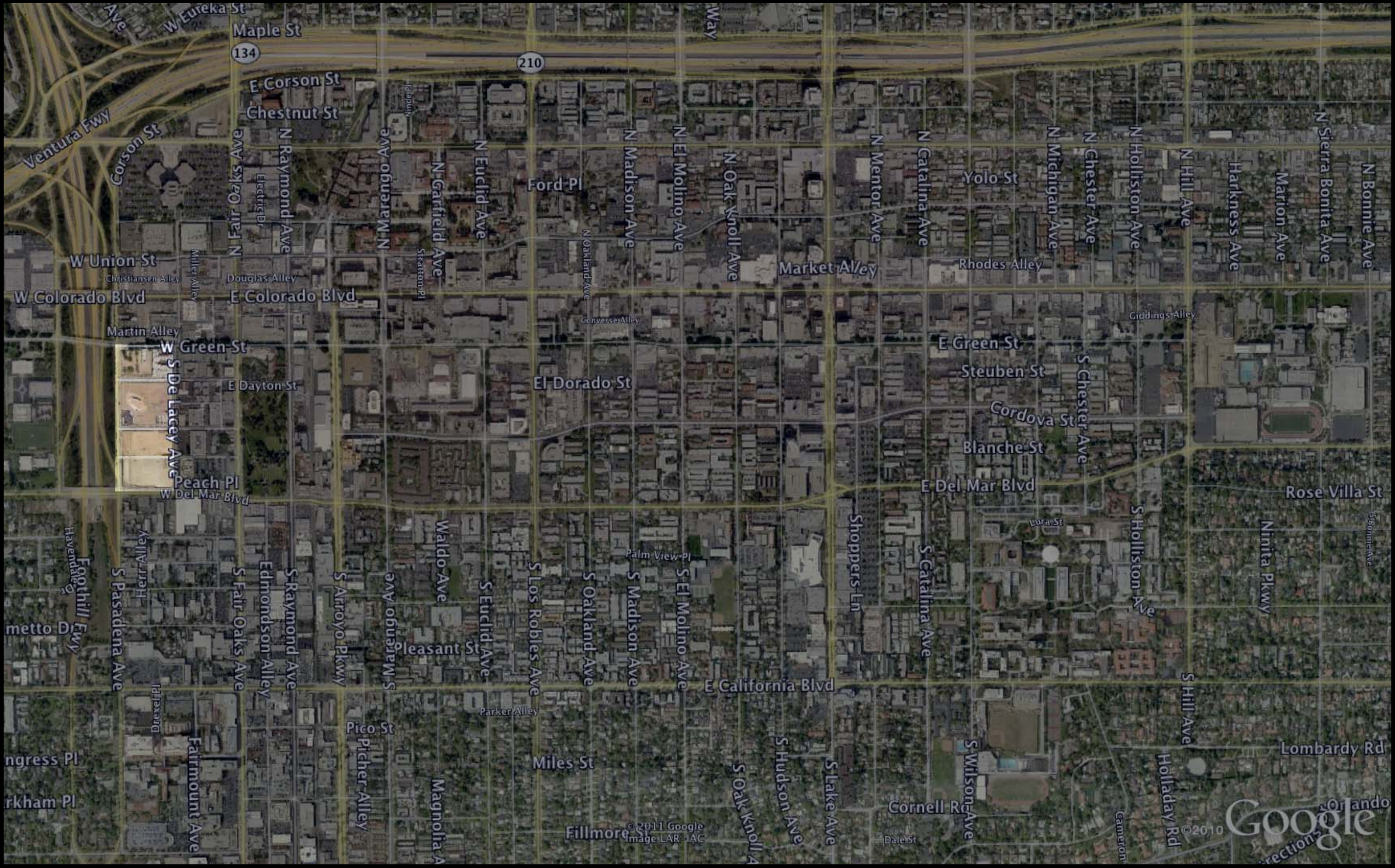
Damage decorrelation: $1 - \gamma_D$



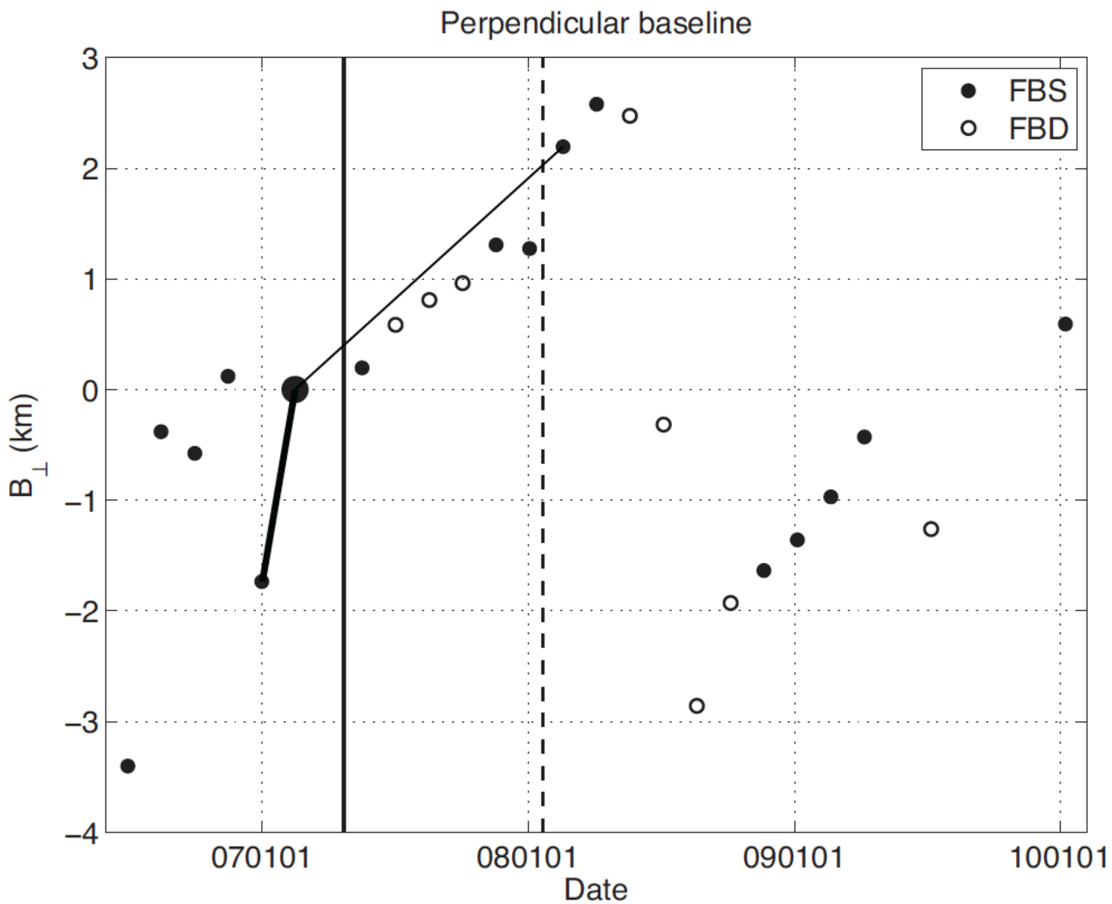
$$
\begin{aligned}
\Delta\gamma &= \gamma^0 - \gamma^1\gamma_D^1 \\
&= (1 - \gamma_D^1)\gamma^0 + (\gamma^0 - \gamma^1)\gamma_D^1
\end{aligned}
$$

Objective: Spatially isolate damage decorrelation for automatic detection

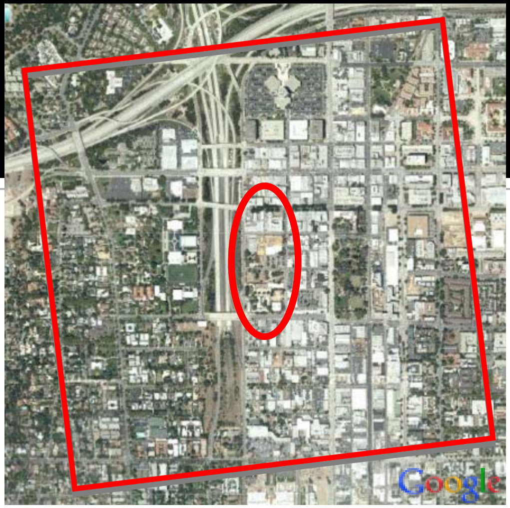
Algorithm Test:
Pasadena Building Demolition Project (IEEE TGRS, in prep)

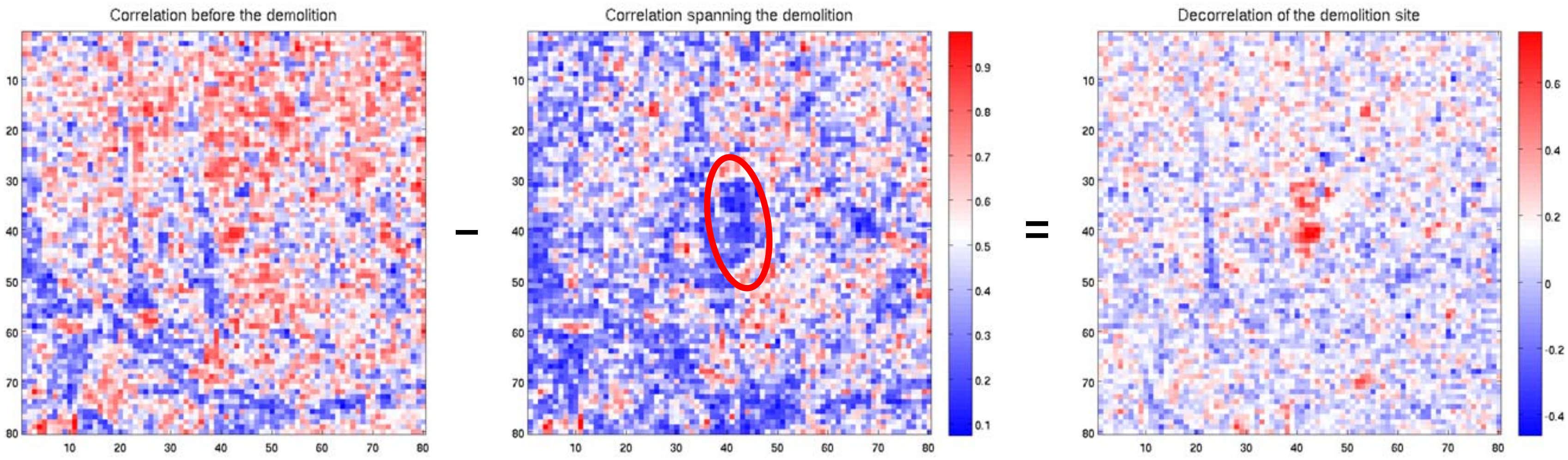


Data: ALOS PALSAR

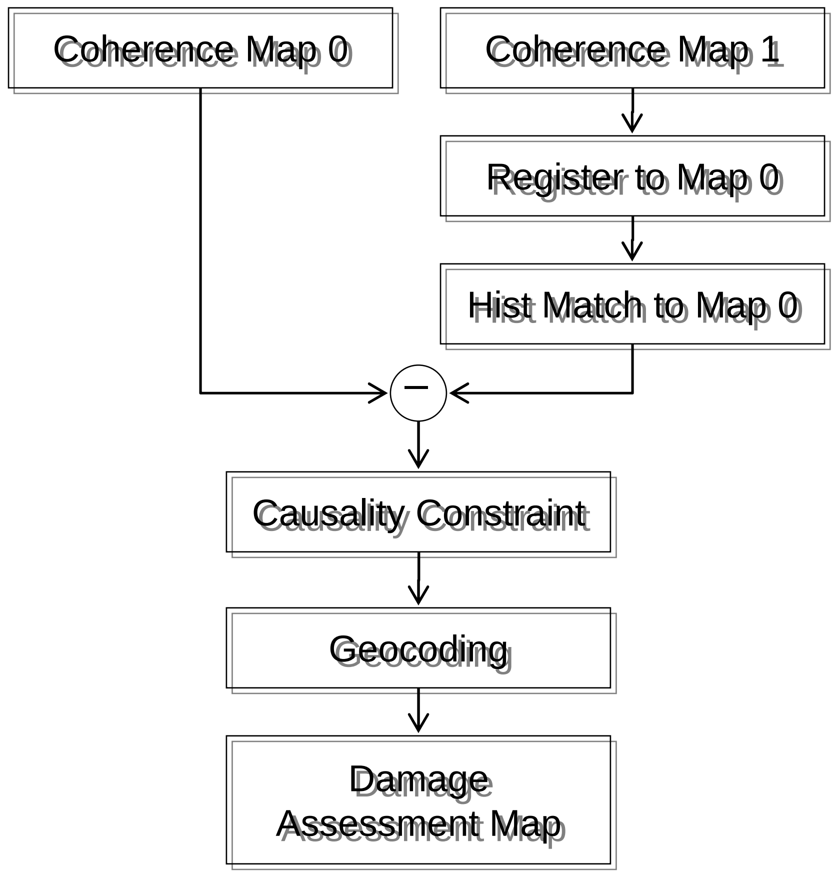


Simple Difference

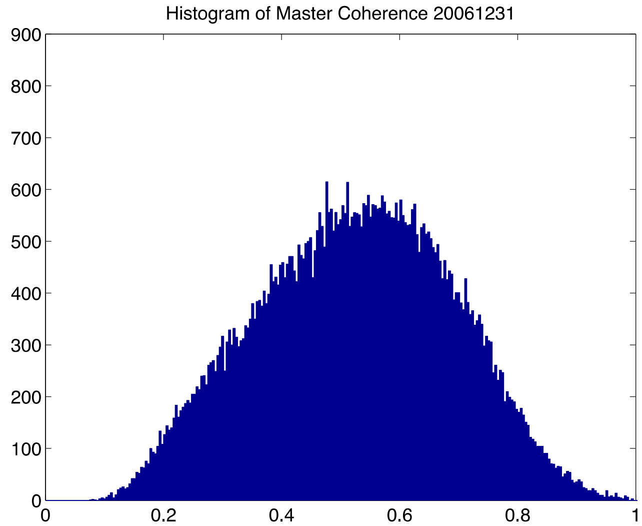




Workflow


Coherence Map 0
Coherence Map 1
Register to Map 0
Hist Match to Map 0
−
Causality Constraint
Geocoding
Damage
Assessment Map

Histogram Matching (Coltuc et al., IEEE TIP 2006)



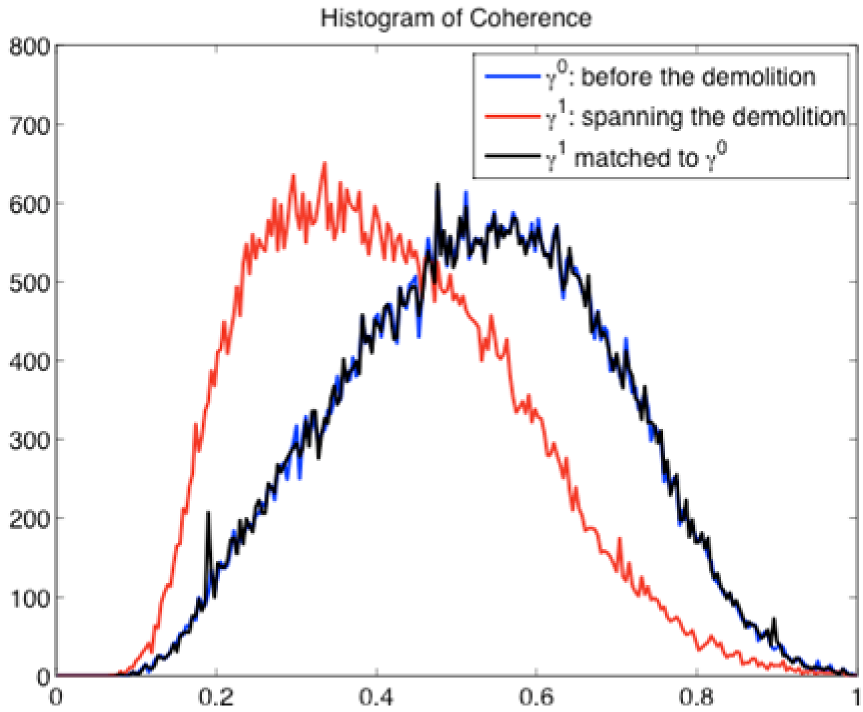
$$F_X(x) = \mathrm{P}\{X \le x\} = \int_{-\infty}^{x} p_X(r)\, dr$$

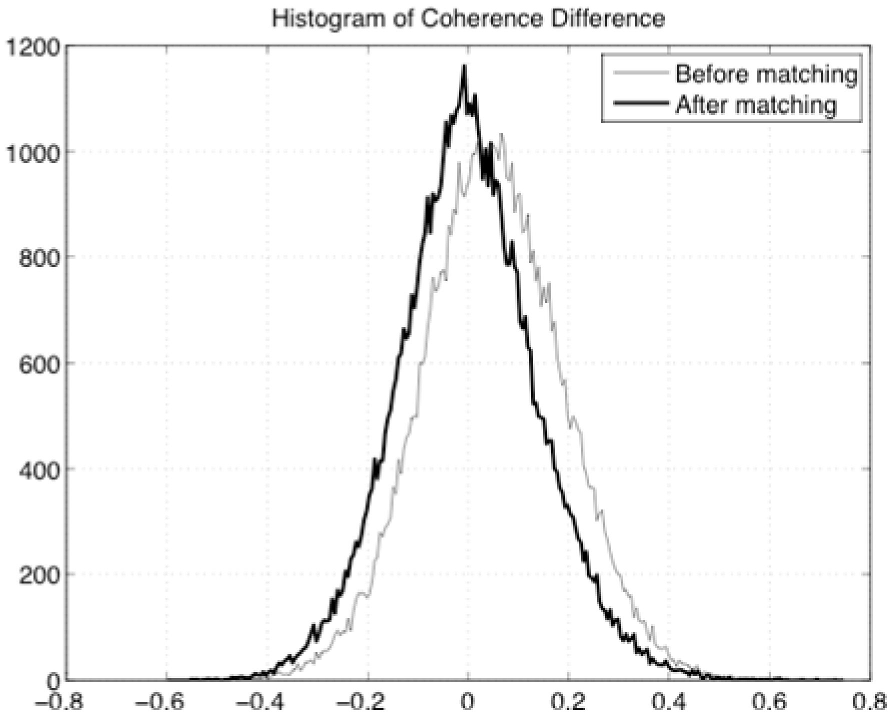
$$F_Y(y) = \mathrm{P}\{Y \le y\} = \int_{-\infty}^{y} p_Y(r)\, dr$$

$$\begin{aligned} F_Y(y) &= \mathrm{P}\{Y \le y\} \\ &= \mathrm{P}\{F(X) \le y\} \\ &= \mathrm{P}\{X \le F^{-1}(y)\} \\ &= F(F^{-1}(y)) = y, \quad \text{for } 0 \le \mathrm{y} \le 1 \end{aligned}$$

- For a continuous random variable X, Y = $F_X(X)$ is another continuous random variable that has a uniform distribution in [0 1].
- Thus, it follows that if a random variable Y has a uniform distrubution in [0 1], then X = $F_X^{-1}(Y)$ has a pdf of $p_x(X)$.
- Therefore, X = $F_X^{-1}(F_Y(Y))$ follows $p_X(X)$, where X: master coherence, Y: slave coherence

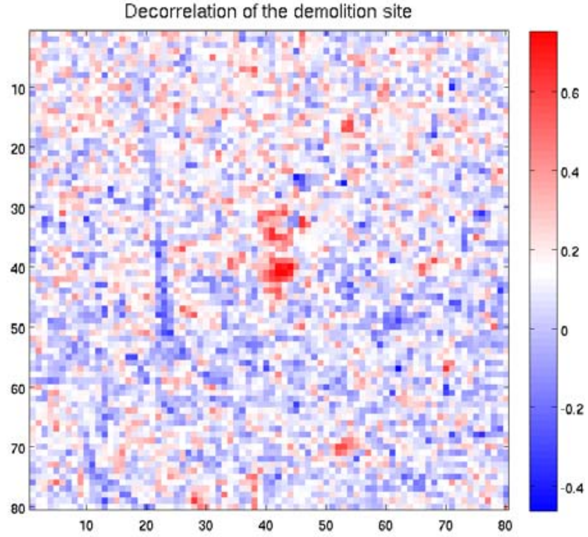
Histogram matching removes bias



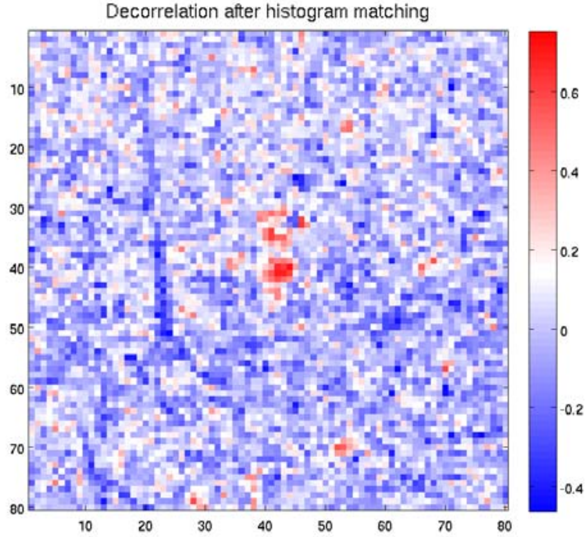


Results

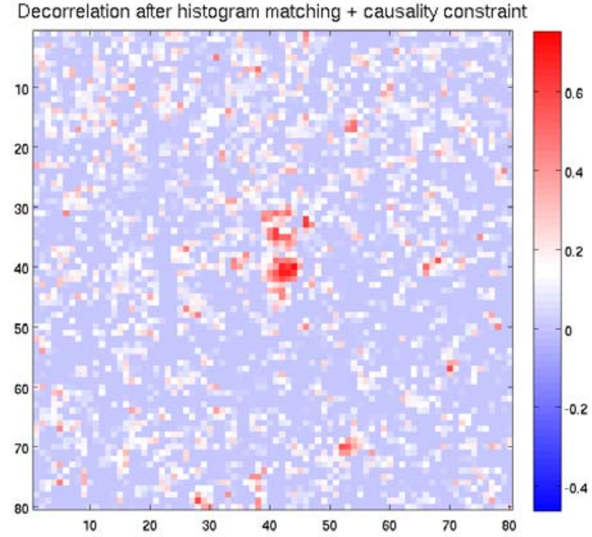
Simple Difference
SNR = 17.3



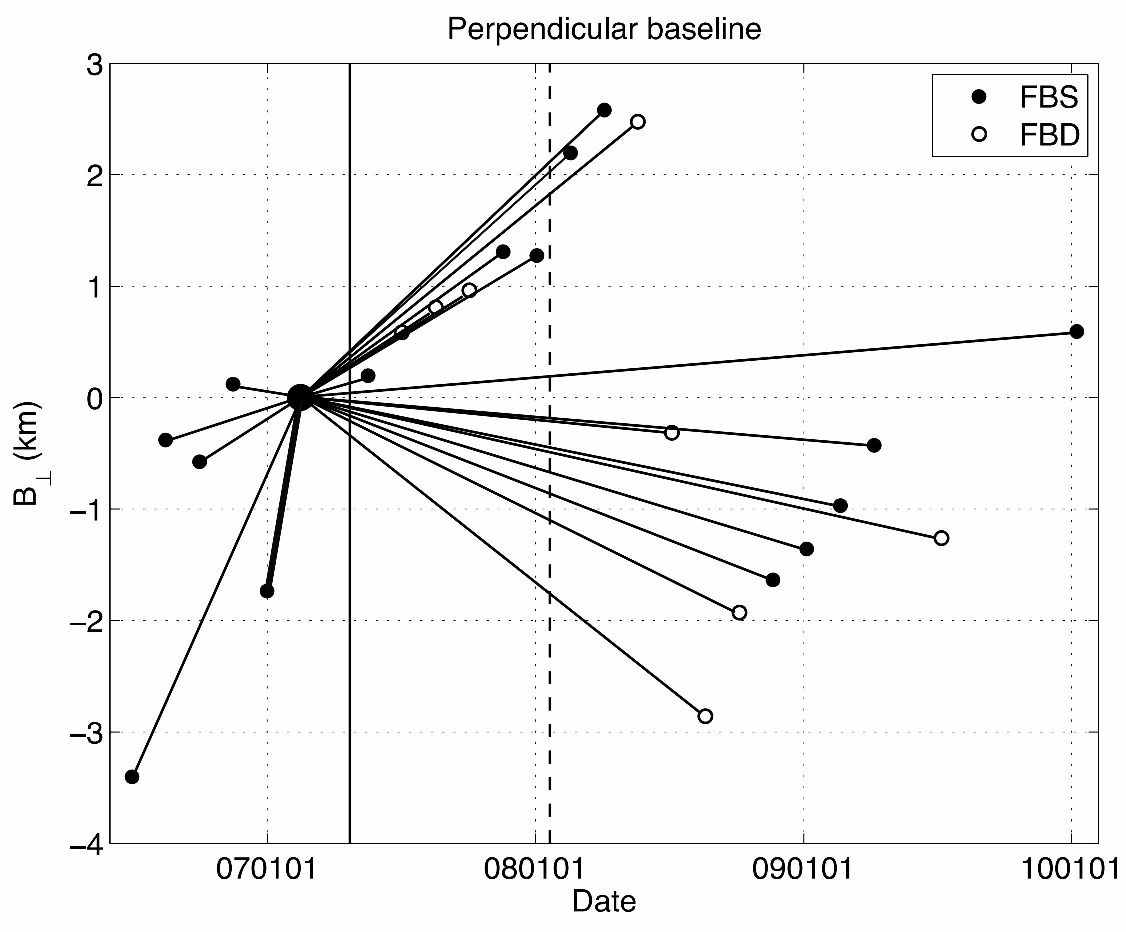
Histogram Matching
SNR = 23.1



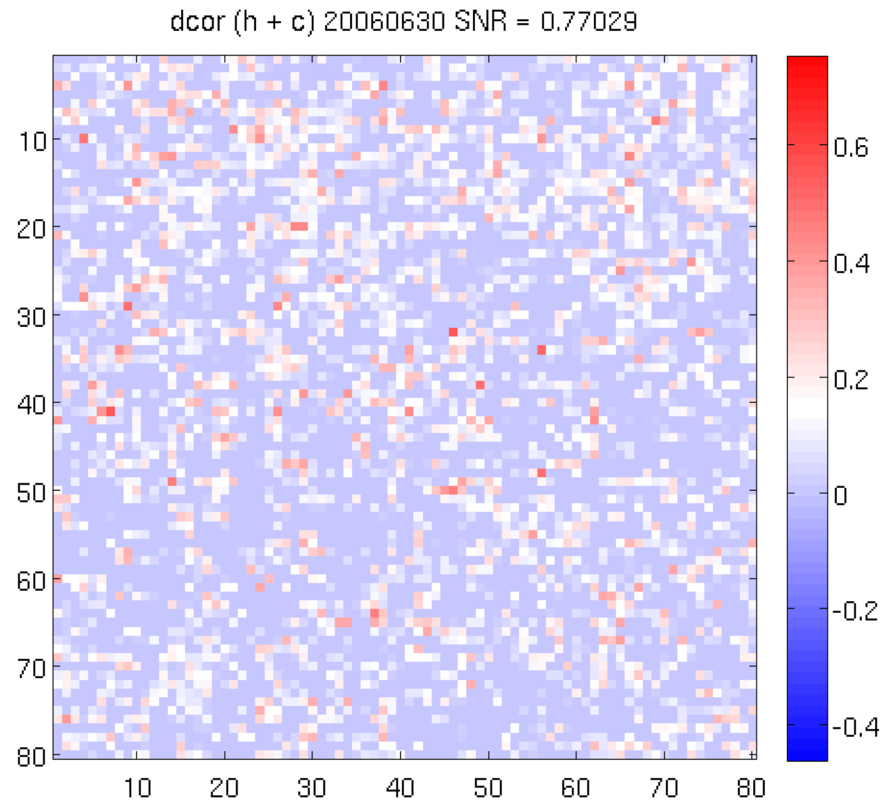
Causality Constraint
SNR = 44.6



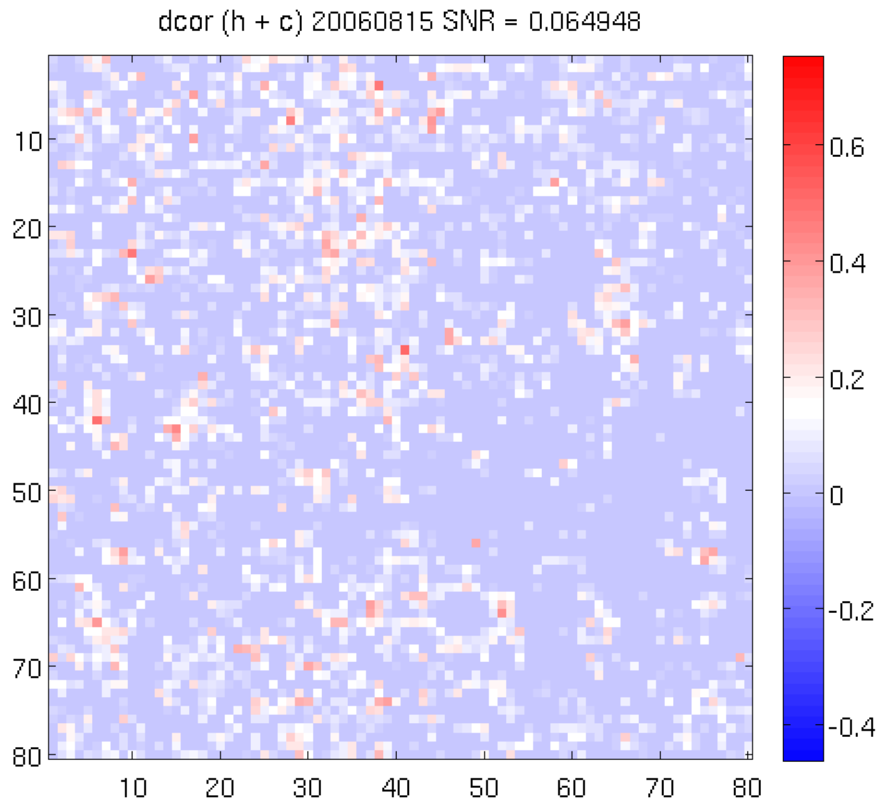
Pairing Scheme for Coherence Change Time Series



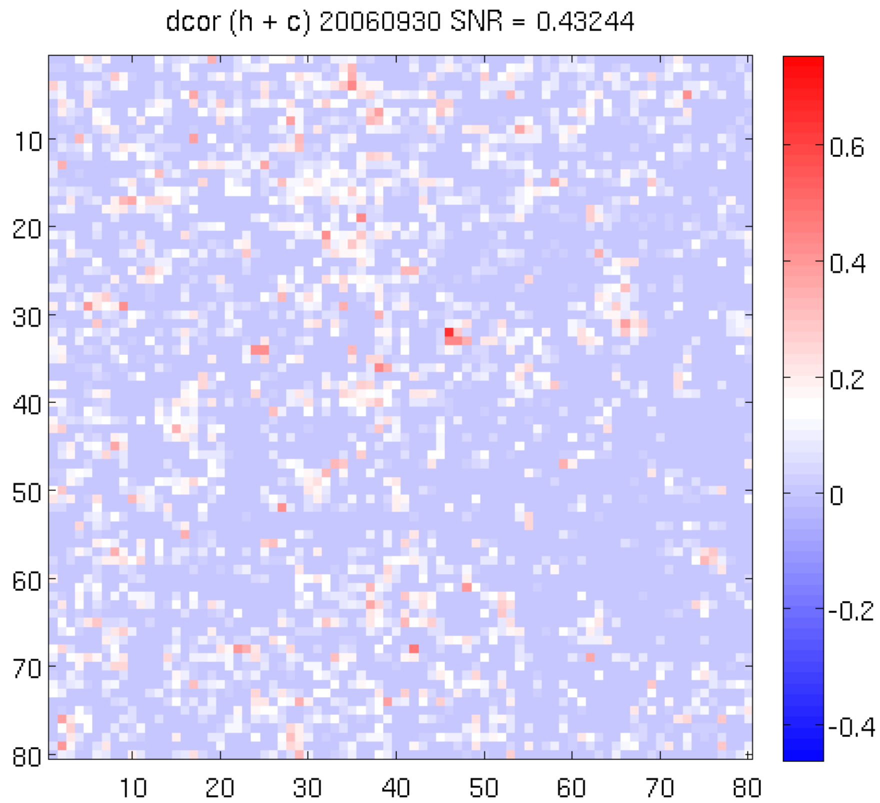
Time Series of Interferometric Coherence Difference



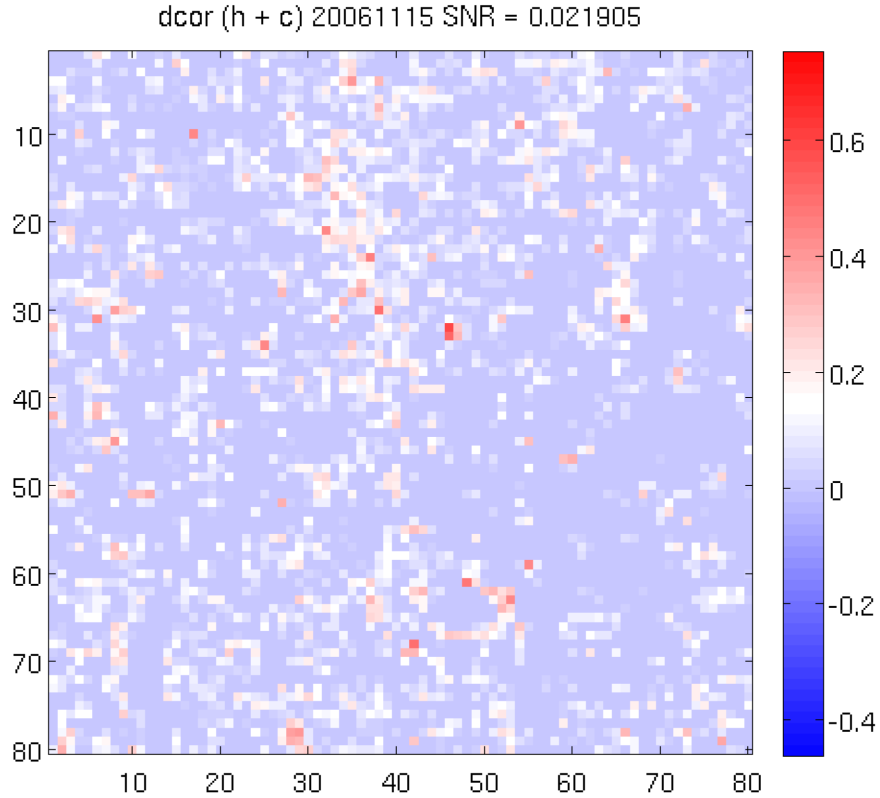
Time Series of Interferometric Coherence Difference



Time Series of Interferometric Coherence Difference



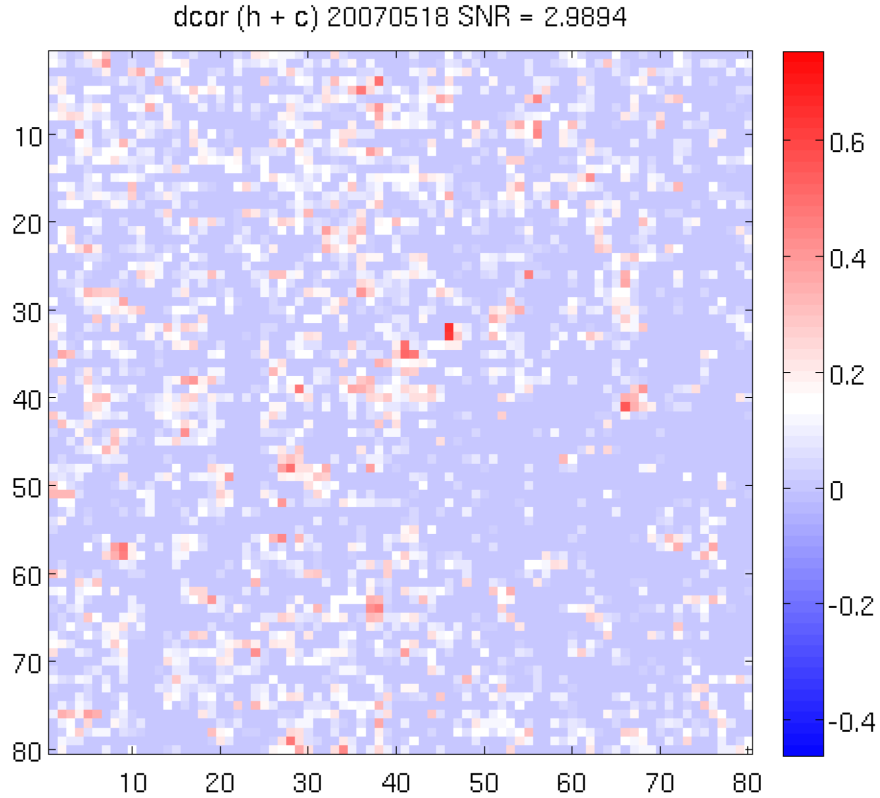
Time Series of Interferometric Coherence Difference



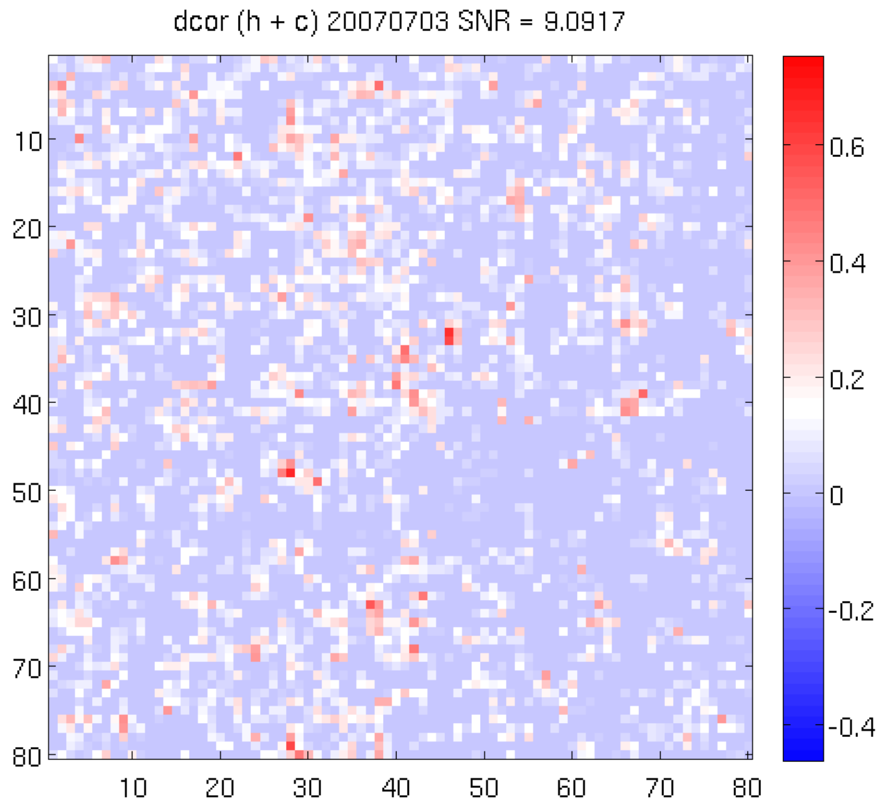
Time Series of Interferometric Coherence Difference

Demolition begins on 2007/04/23.

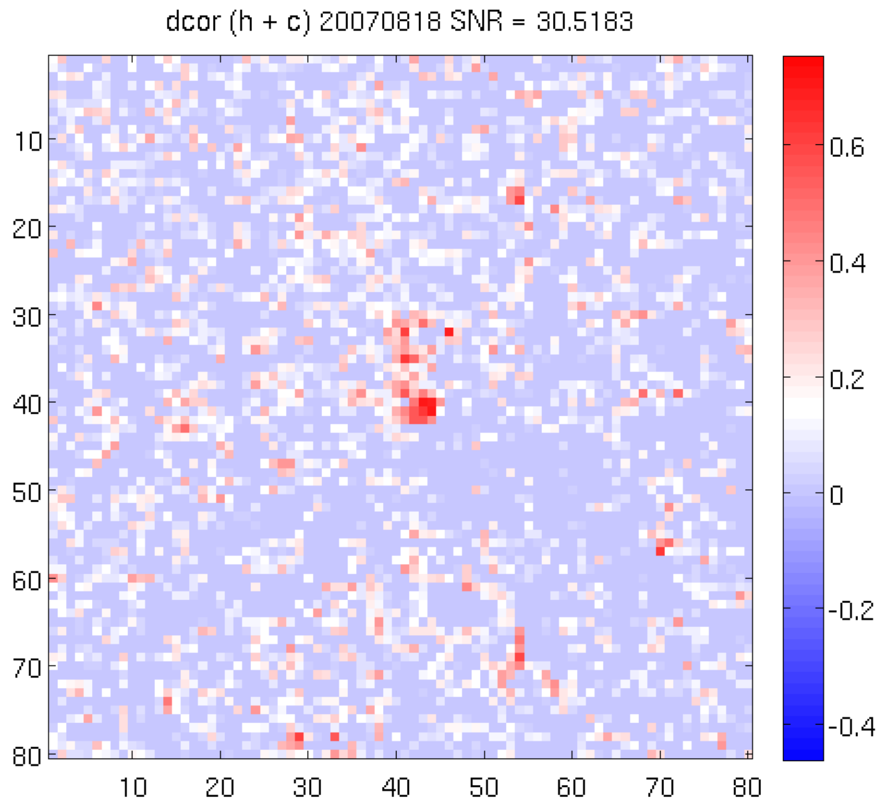
Time Series of Interferometric Coherence Difference



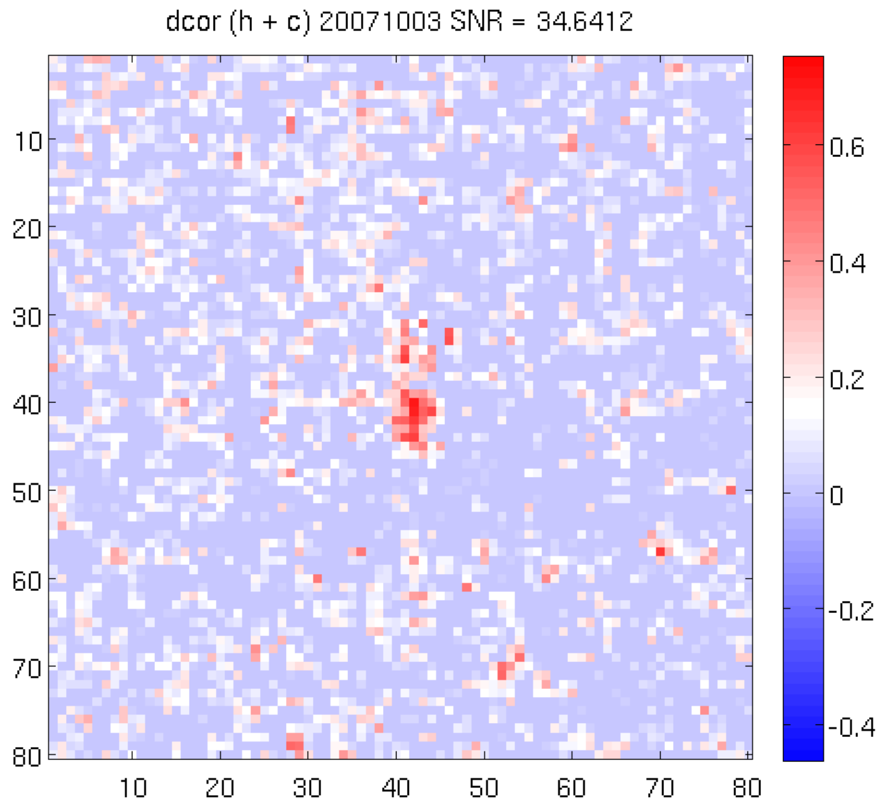
Time Series of Interferometric Coherence Difference



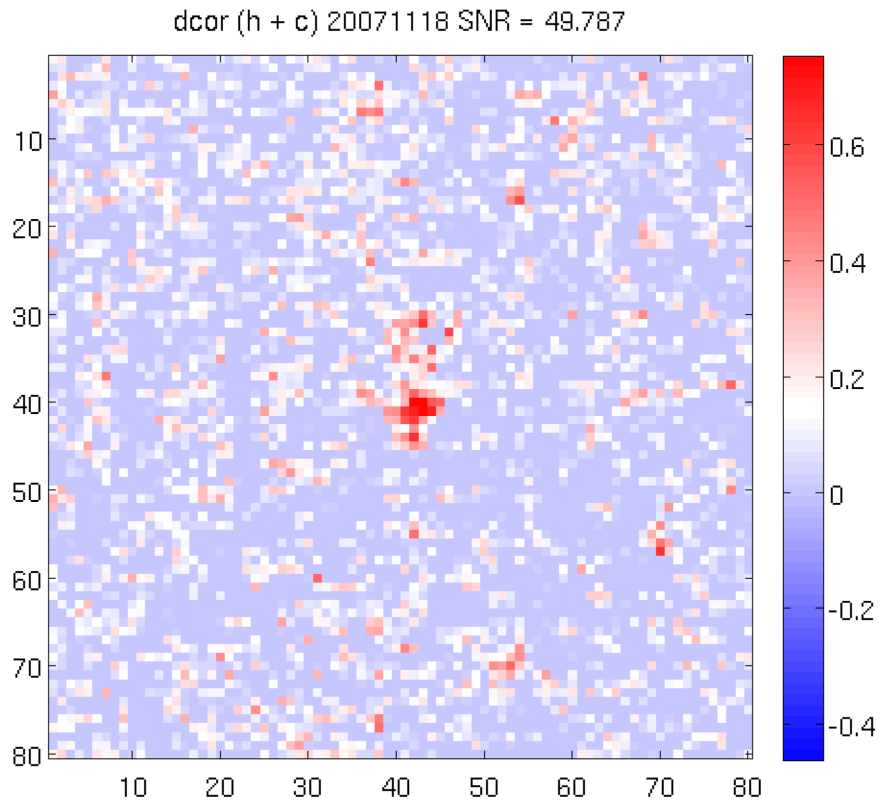
Time Series of Interferometric Coherence Difference



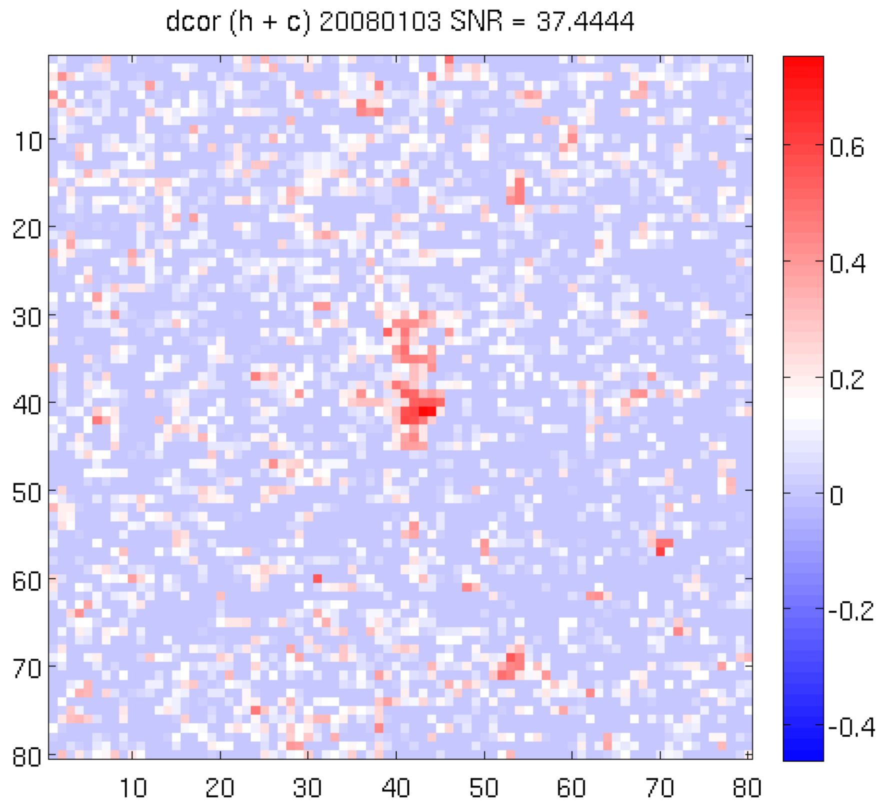
Time Series of Interferometric Coherence Difference



Time Series of Interferometric Coherence Difference



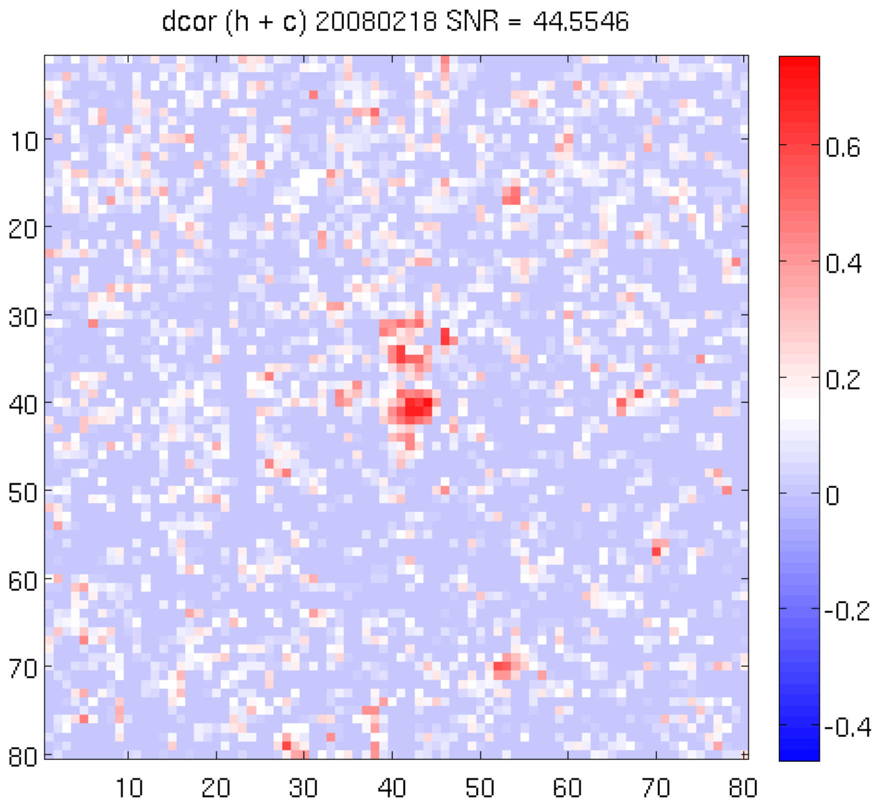
Time Series of Interferometric Coherence Difference



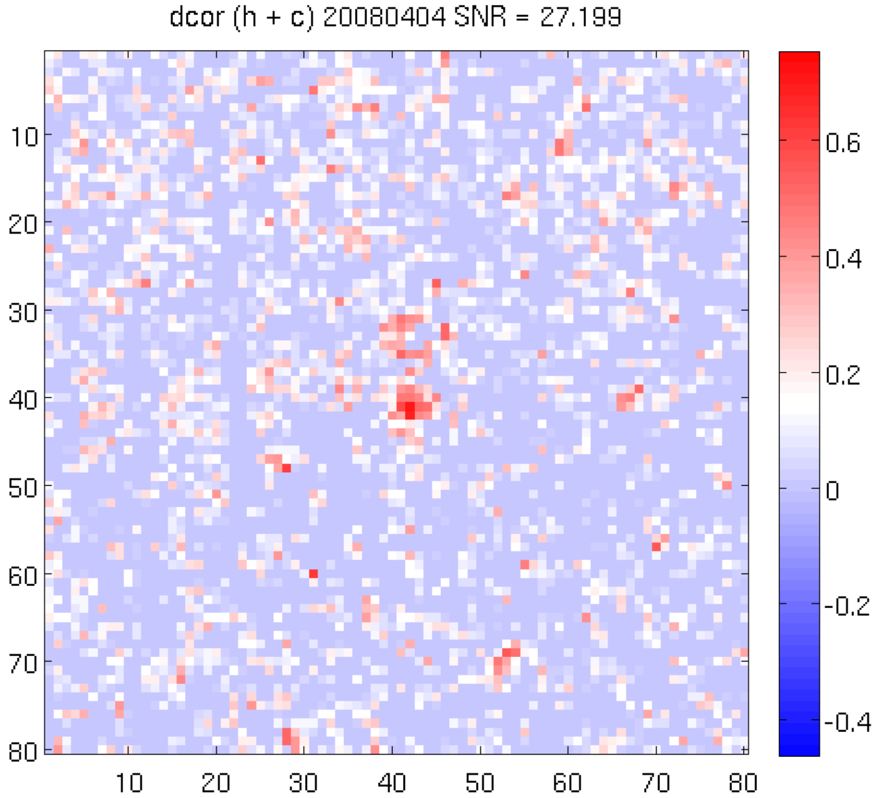
Time Series of Interferometric Coherence Difference

Demolition ends on 2008/01/22.

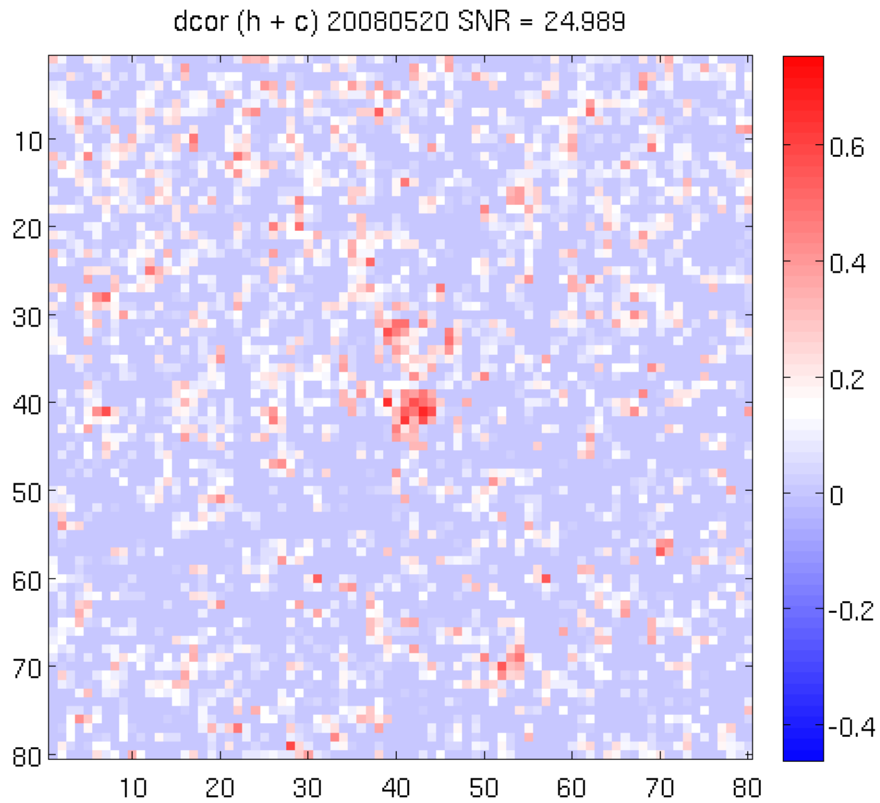
Time Series of Interferometric Coherence Difference



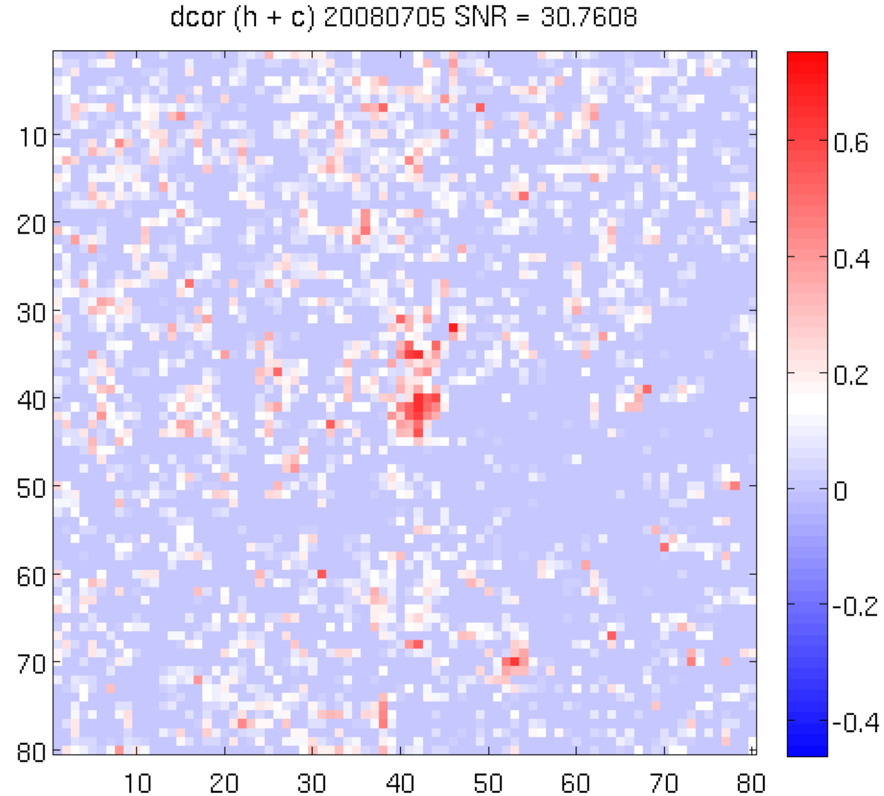
Time Series of Interferometric Coherence Difference



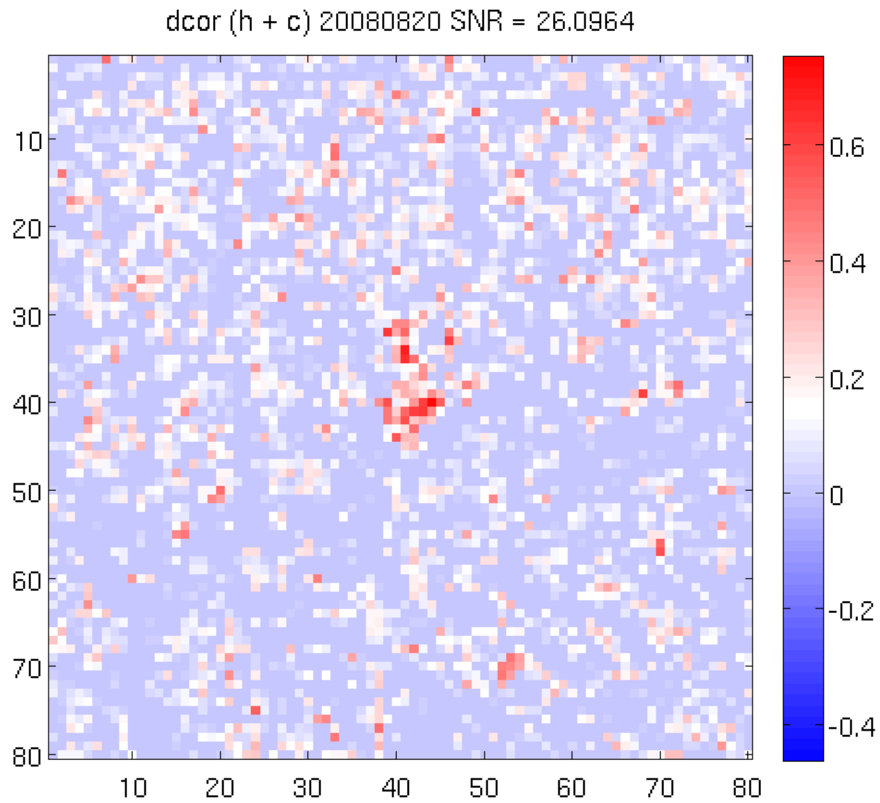
Time Series of Interferometric Coherence Difference



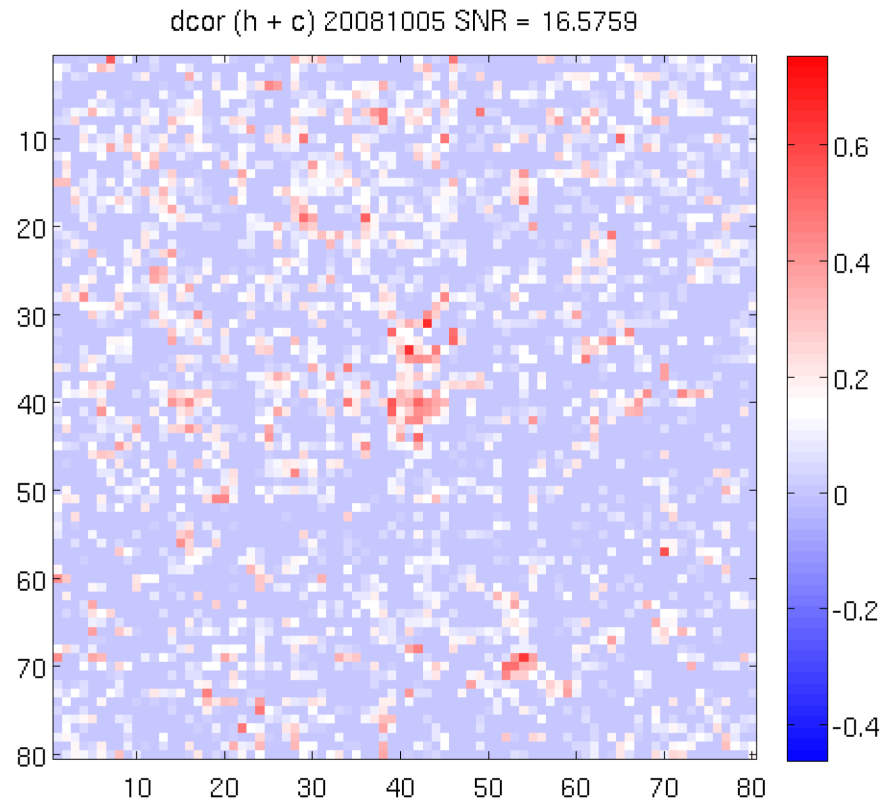
Time Series of Interferometric Coherence Difference



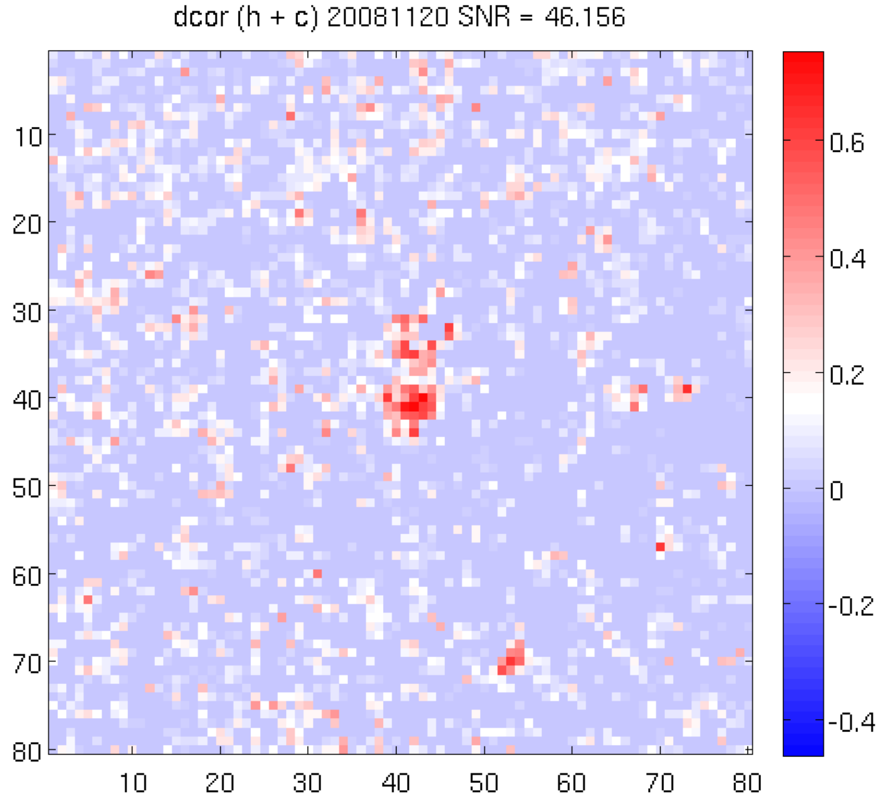
Time Series of Interferometric Coherence Difference



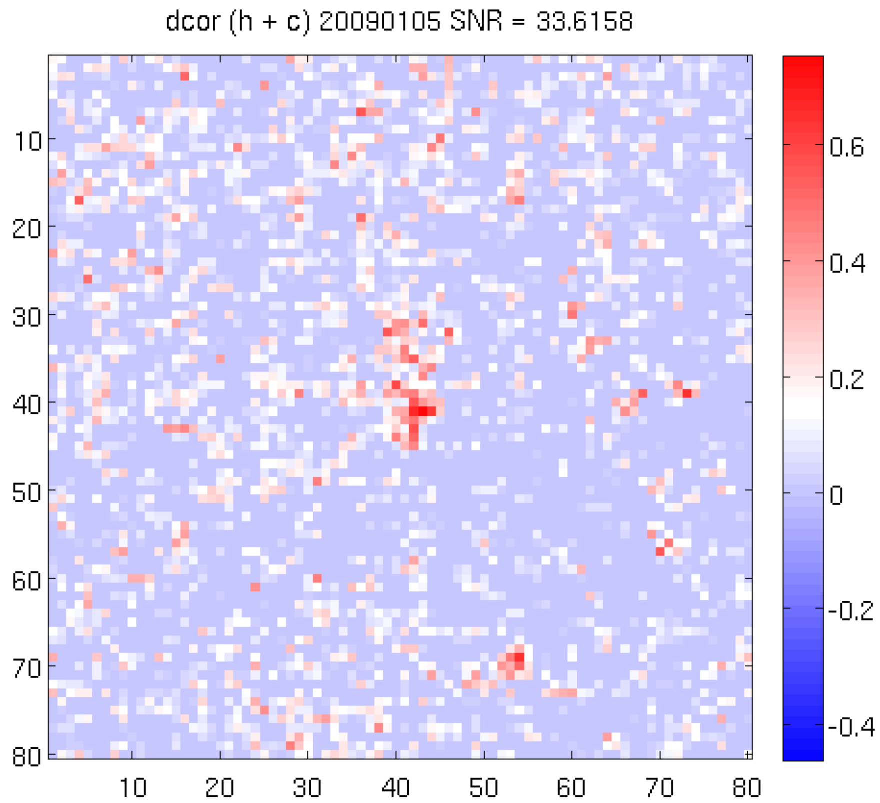
Time Series of Interferometric Coherence Difference



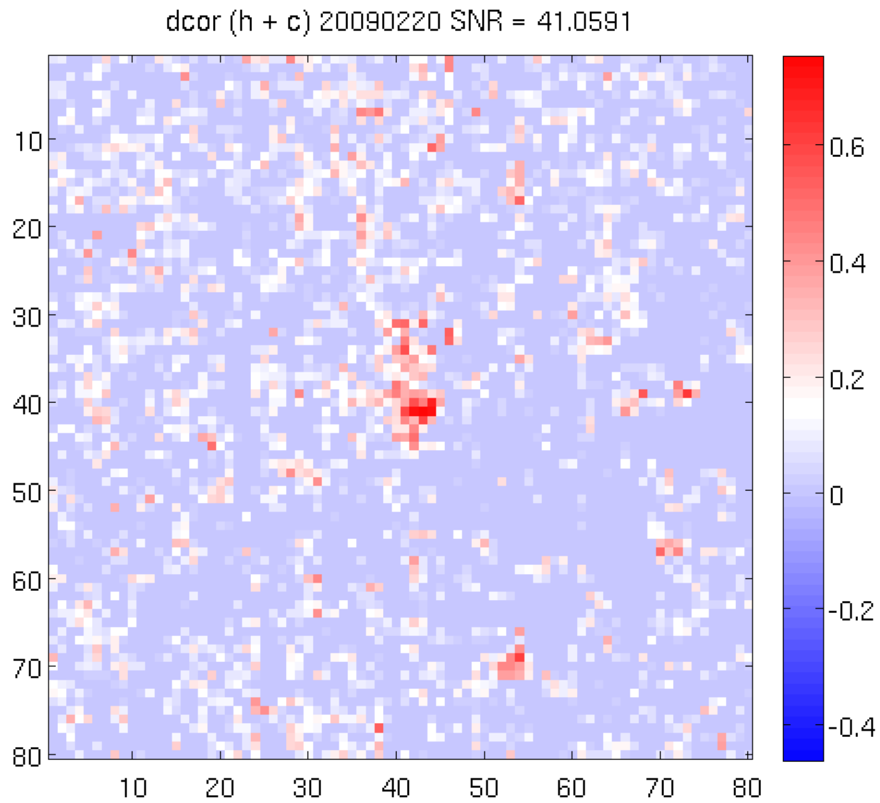
Time Series of Interferometric Coherence Difference



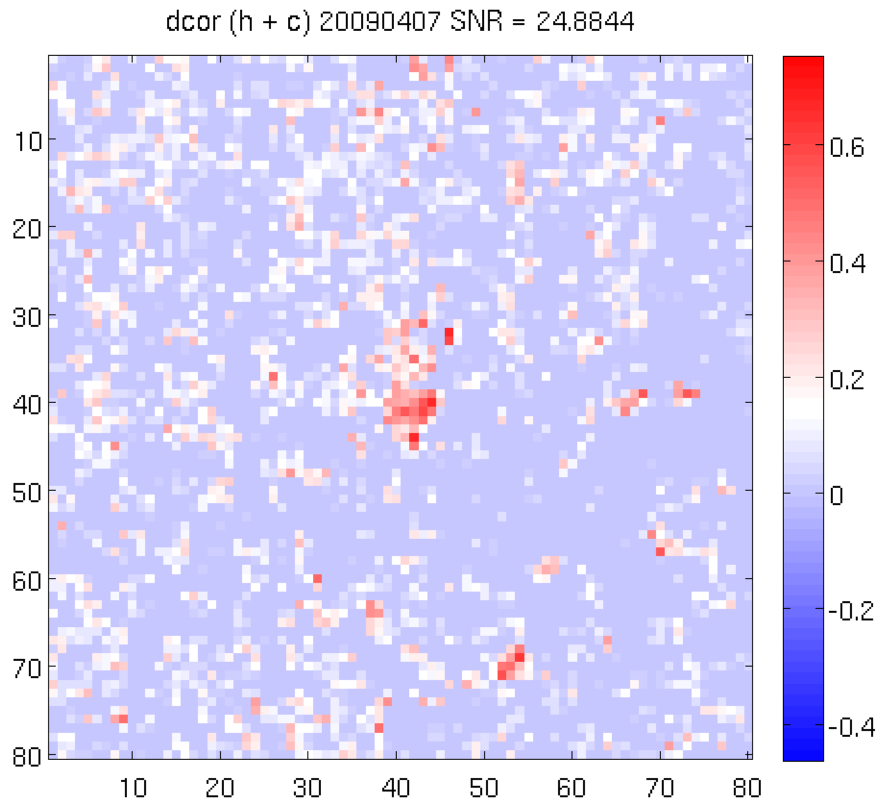
Time Series of Interferometric Coherence Difference



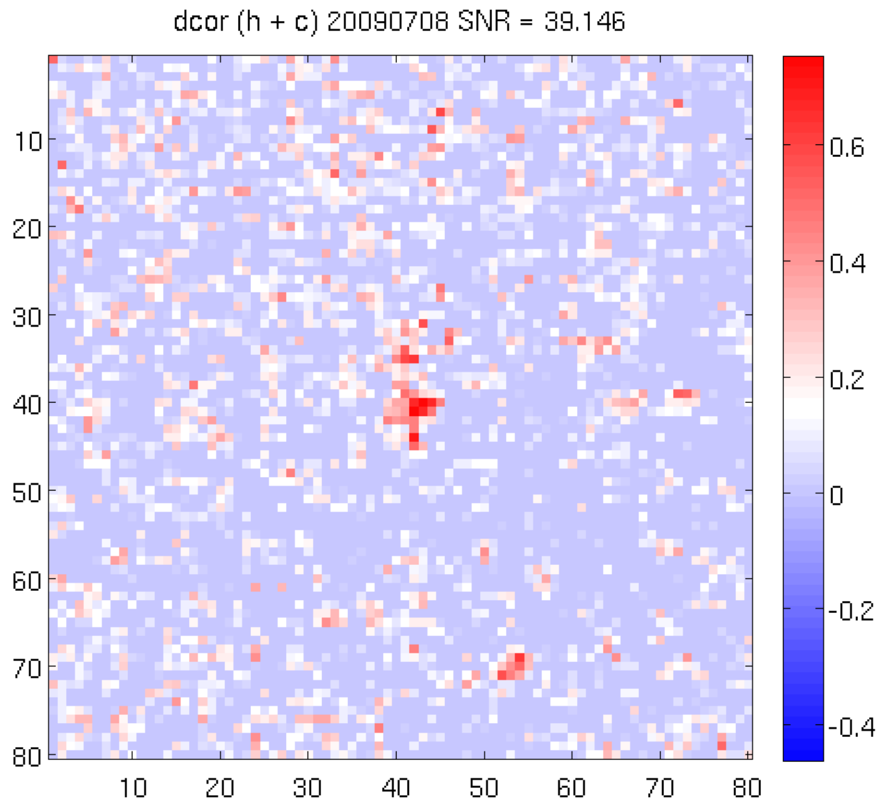
Time Series of Interferometric Coherence Difference



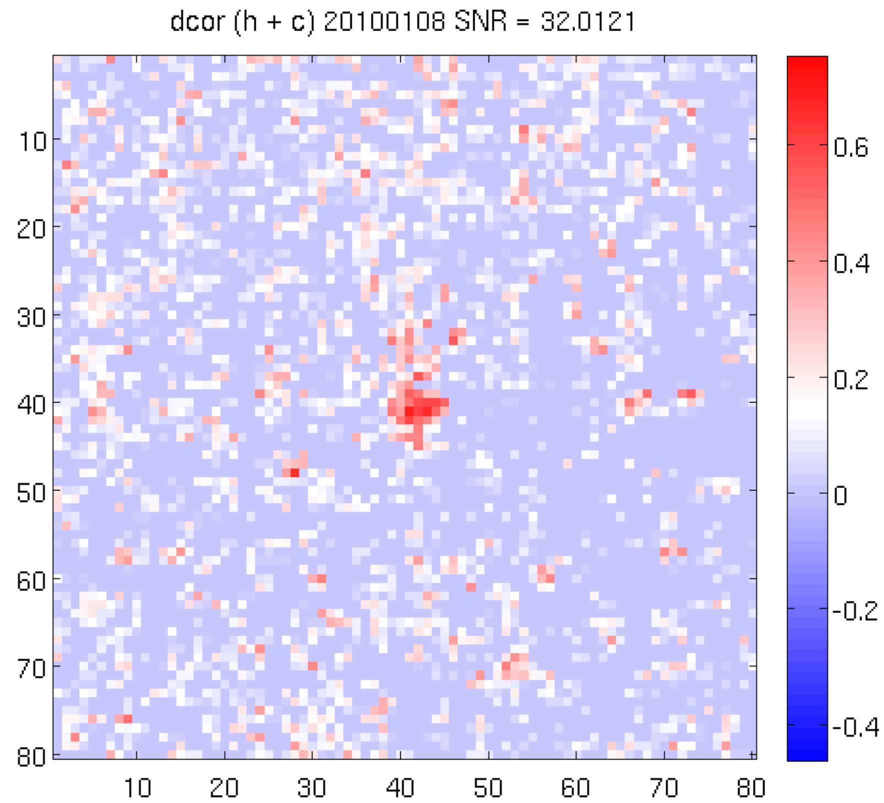
Time Series of Interferometric Coherence Difference



Time Series of Interferometric Coherence Difference

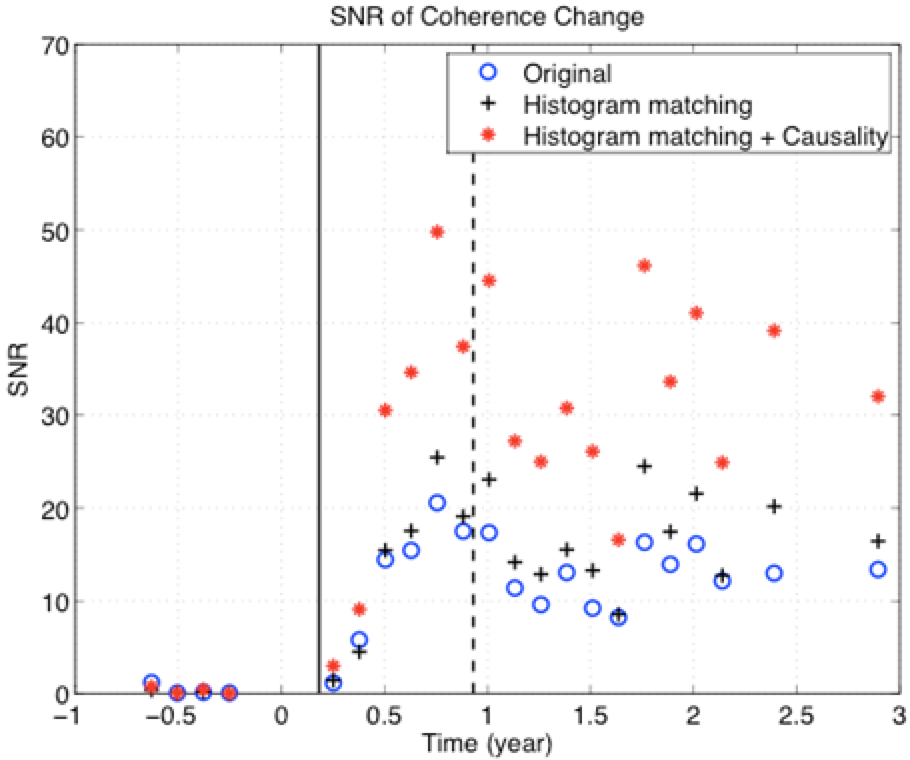


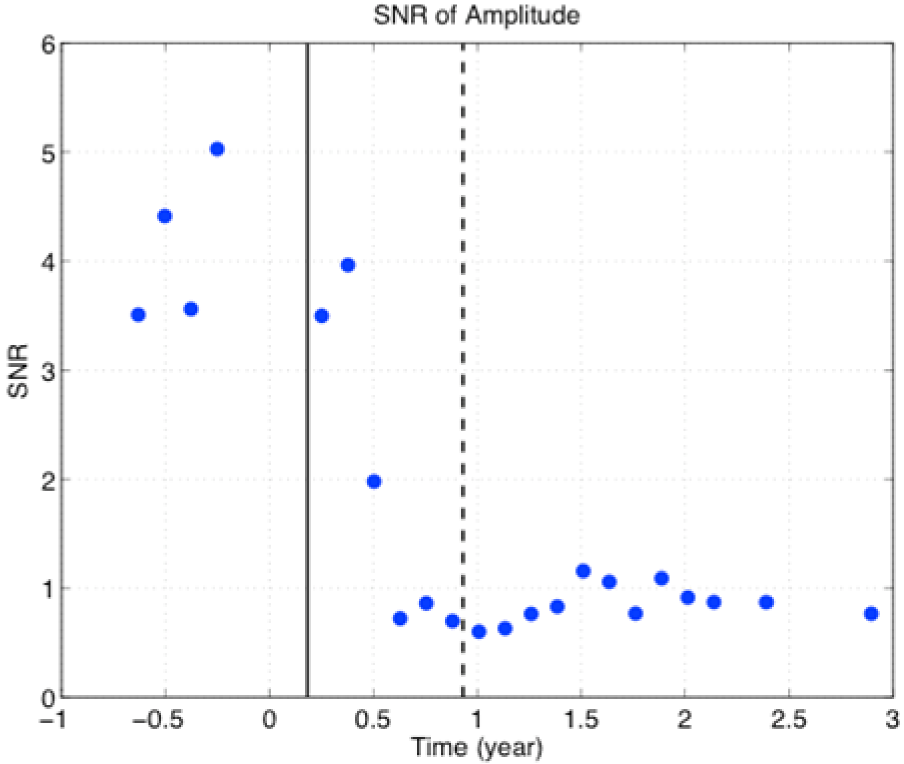
Time Series of Interferometric Coherence Difference



Time Series of SNR

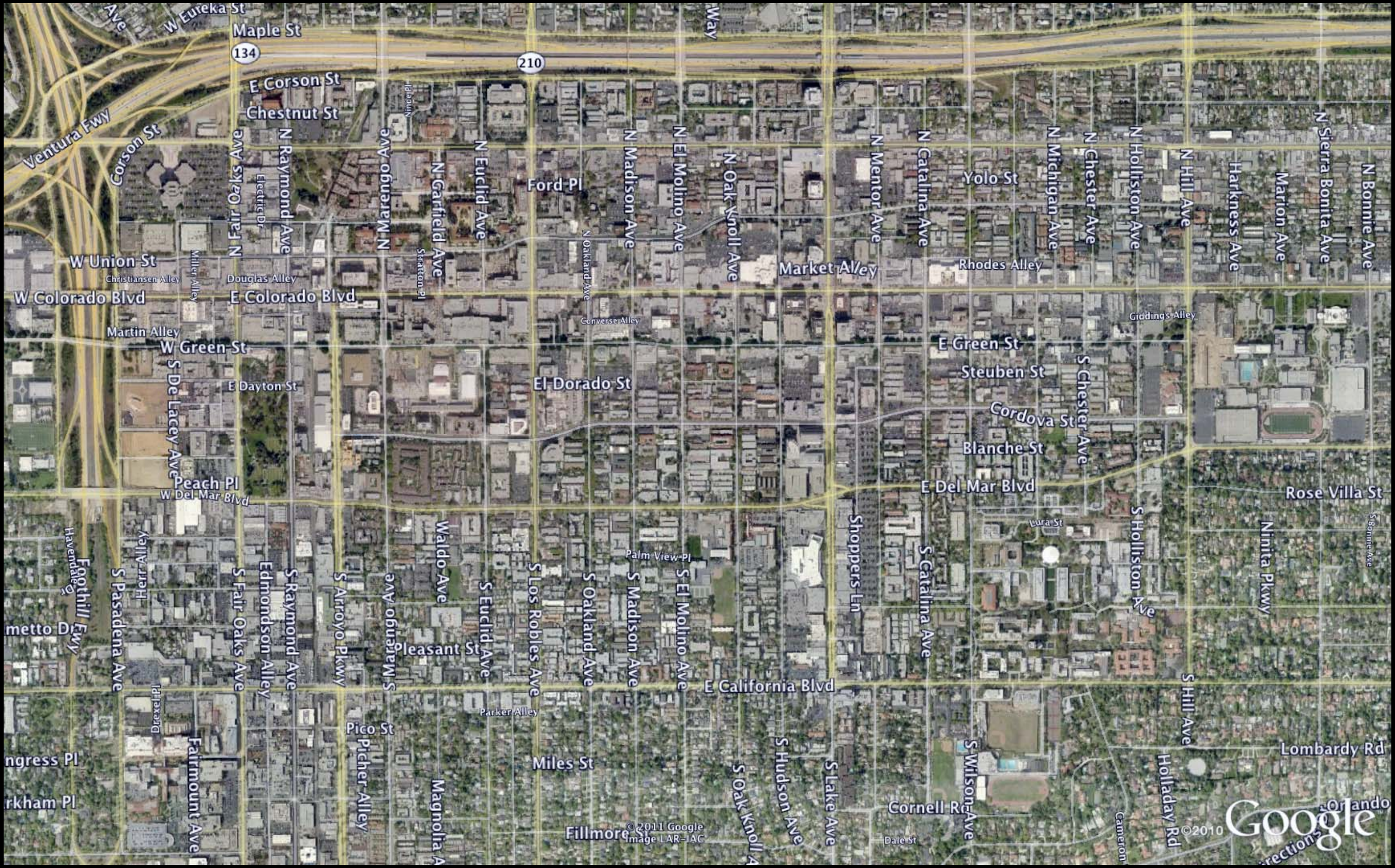
InSAR Coherence Difference and SAR amplitude





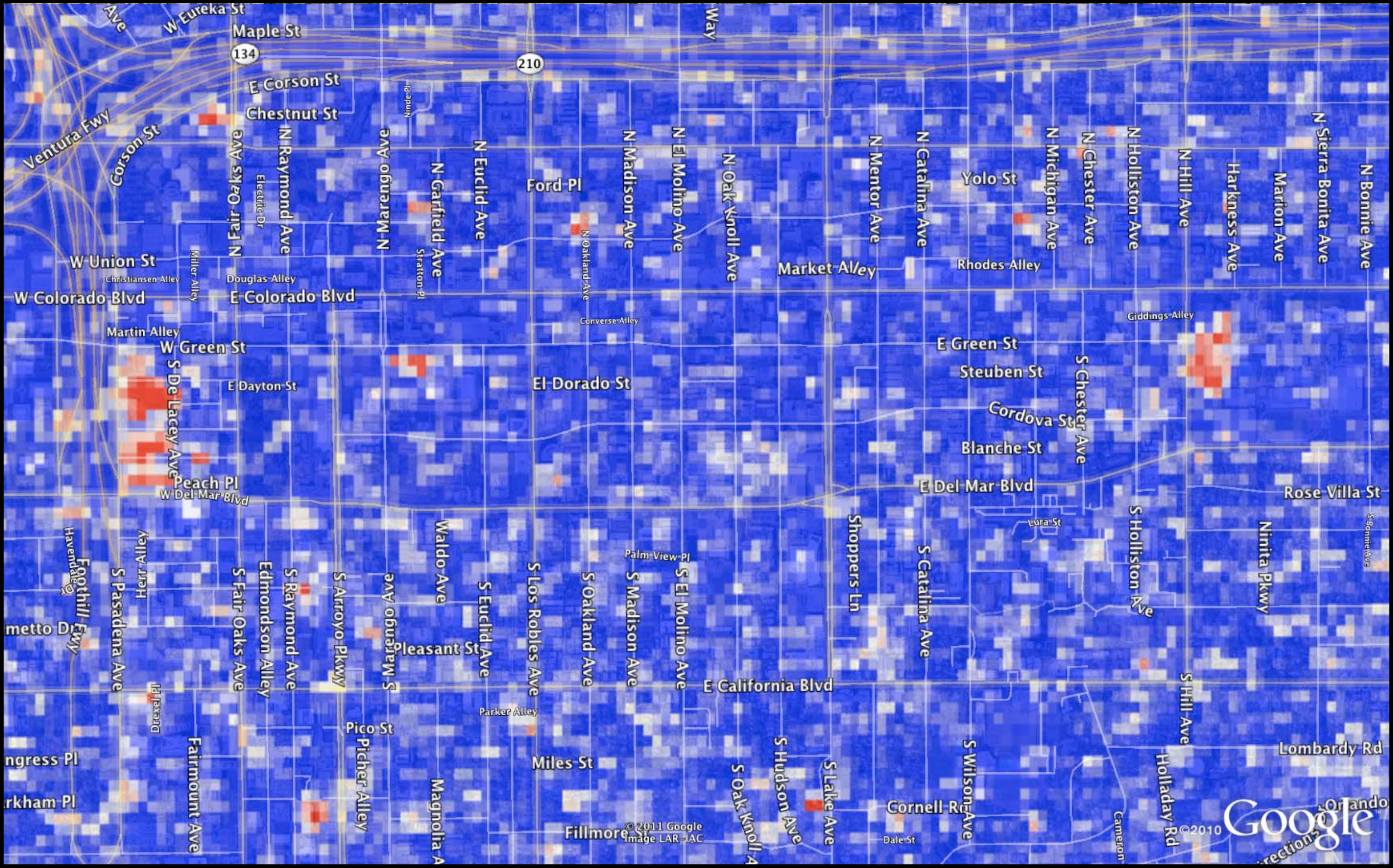
Pasadena

Google Earth Image (20080109)



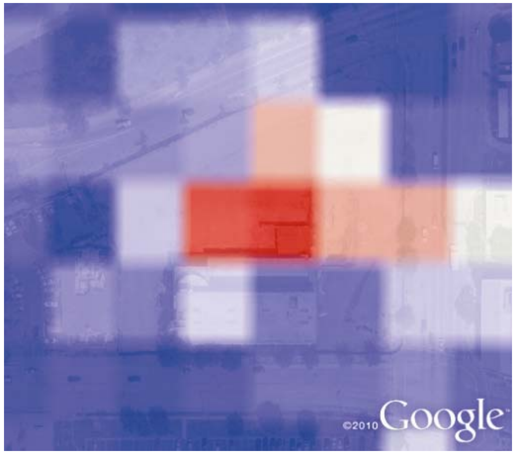
Pasadena

Damage Proxy Map (20061231-20070215-20080218)



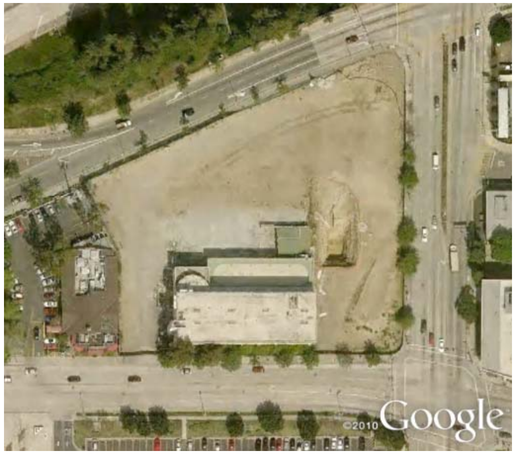
Site 1

Tennis court and parking lot demolished



DPM

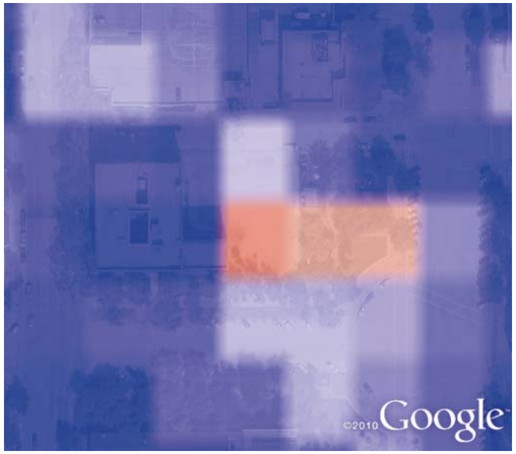
20071023



20080109

Site 2

Flat building demolished



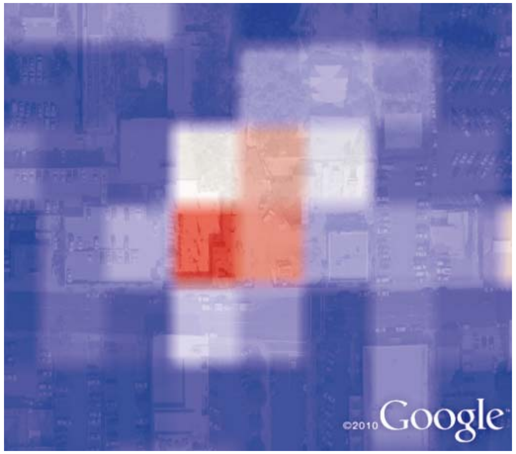
DPM

20071023

20080109

Site 3

Buildings demolished/constructed & Lawn demolished



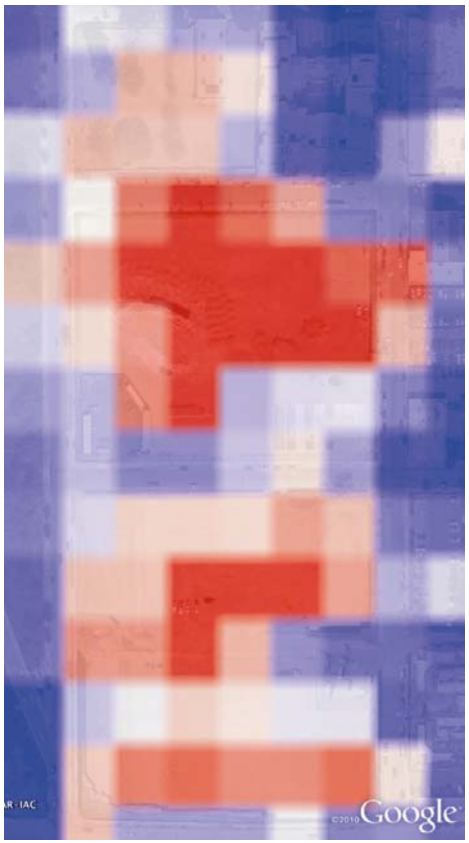
DPM

20071023

20080109

Site 4

Three building blocks demolished for new apartment complex



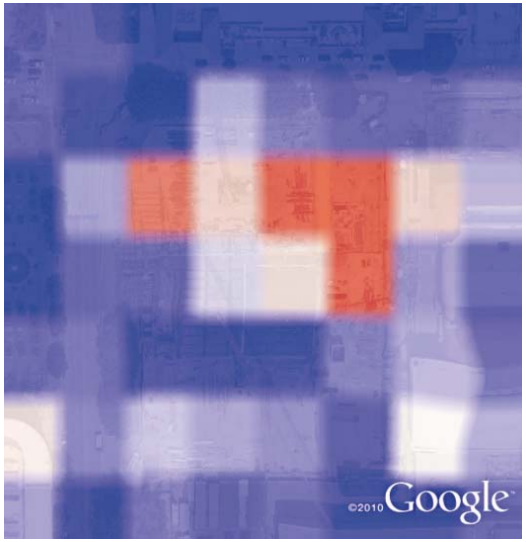
DPM

20071023

20080109

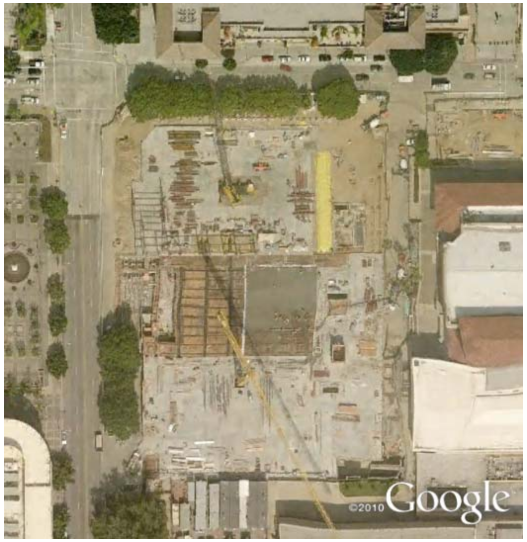
Site 5

Pasadena convention center foundation constructed



DPM

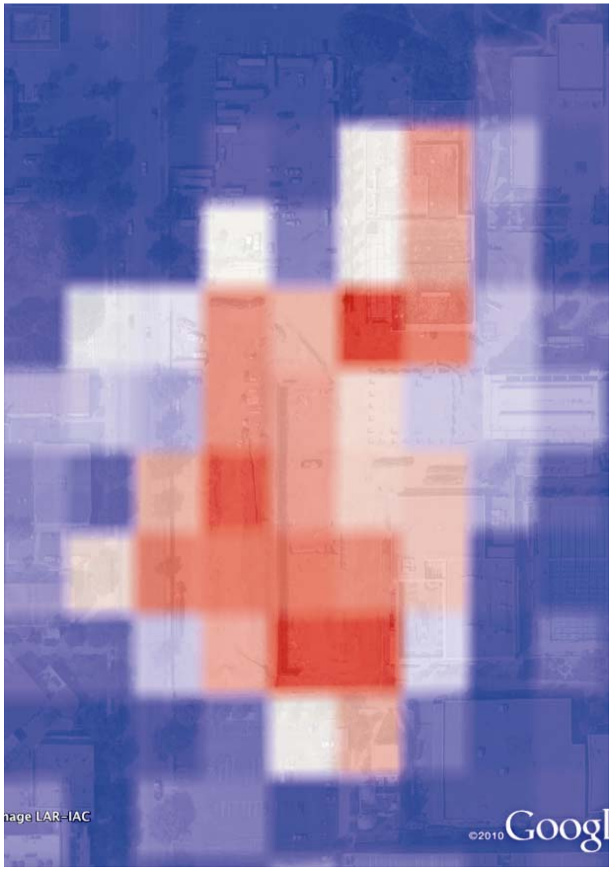
20071023



20080109

Site 6

Pasadena City College tennis court and parking lot demolished for renovation



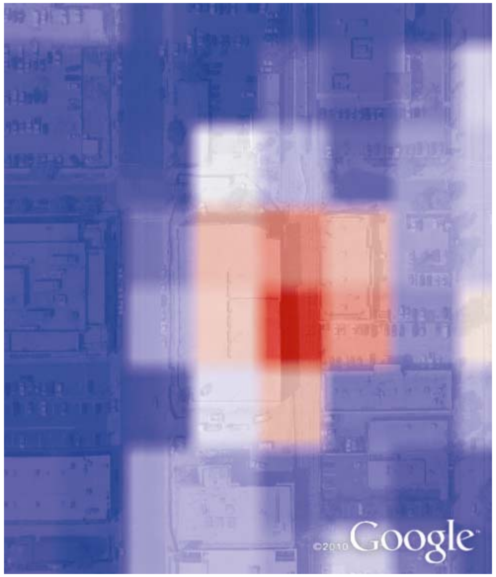
DPM

20071023

20080109

Site 7

Building construction



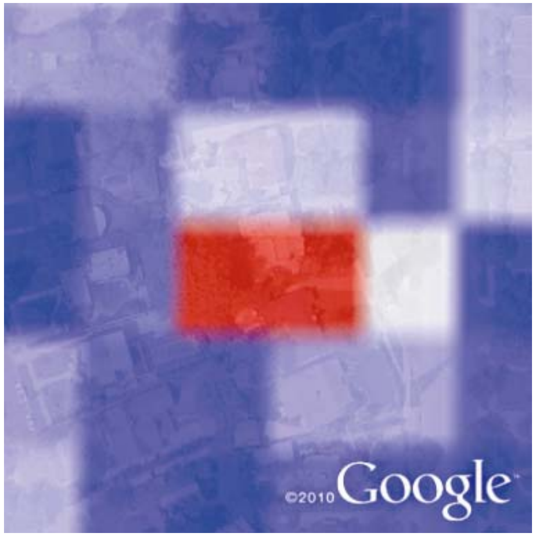
DPM

20071023

20080109

Site 7

Single family house room addition (4 m x 7 m)



DPM

20071023

20080109

Application: Christchurch Earthquake

February 22, 2011
M6.3 Christchurch EQ

At least 181 people were killed

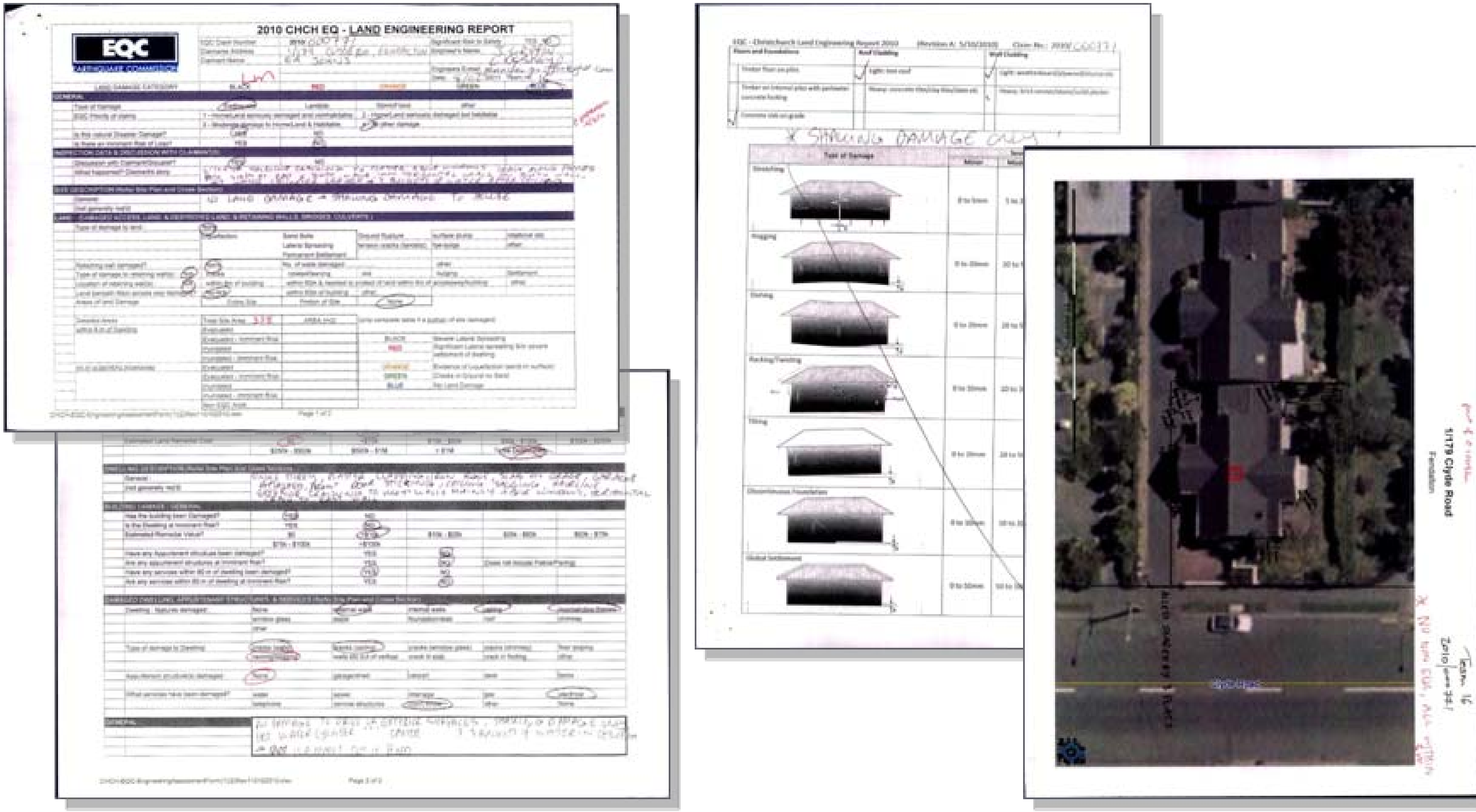
Peak acceleration: 1.88g

Extensive liquefaction producing 400,000 tons of silt

Estimated cost: NZ $15-16 billion

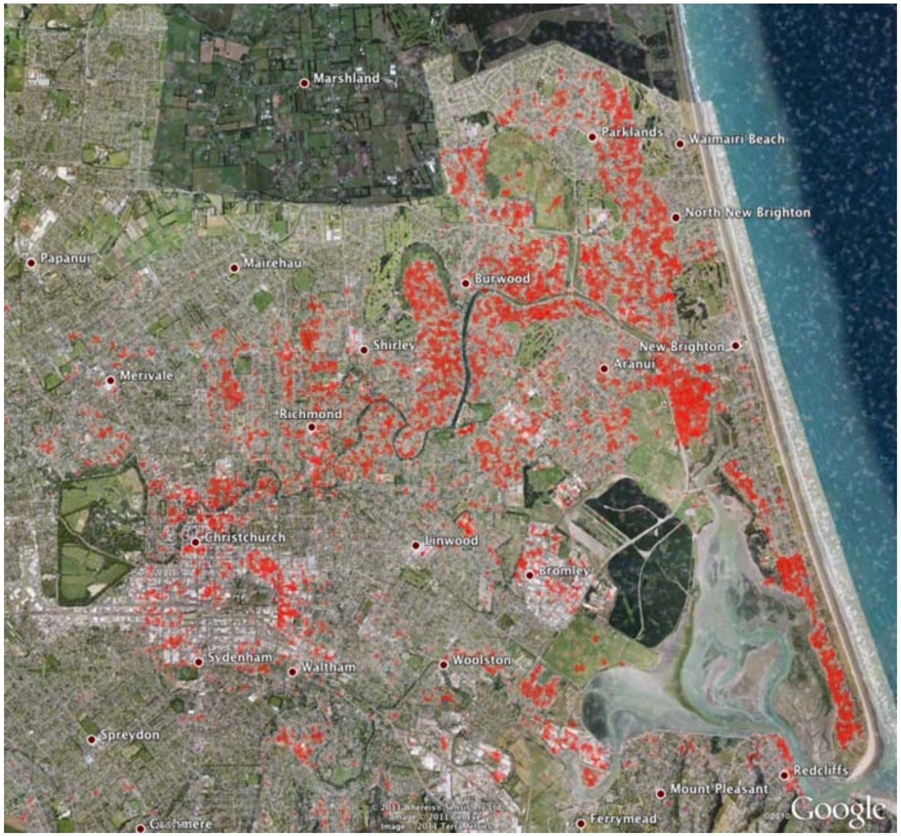
Damage assessment by NZ government under progress

Ground Truth with Engineering Report

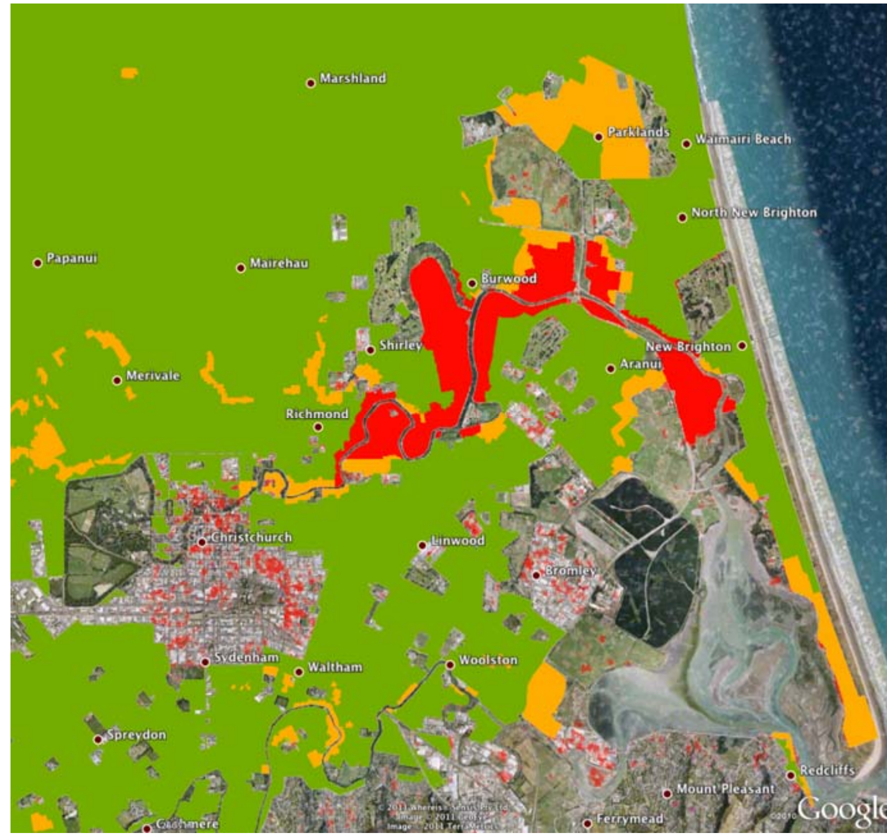


Created by Tonkin & Taylor NZ
for CERA (Christhurch Earthquake Recovery Authority)

DPM vs Ground Truth

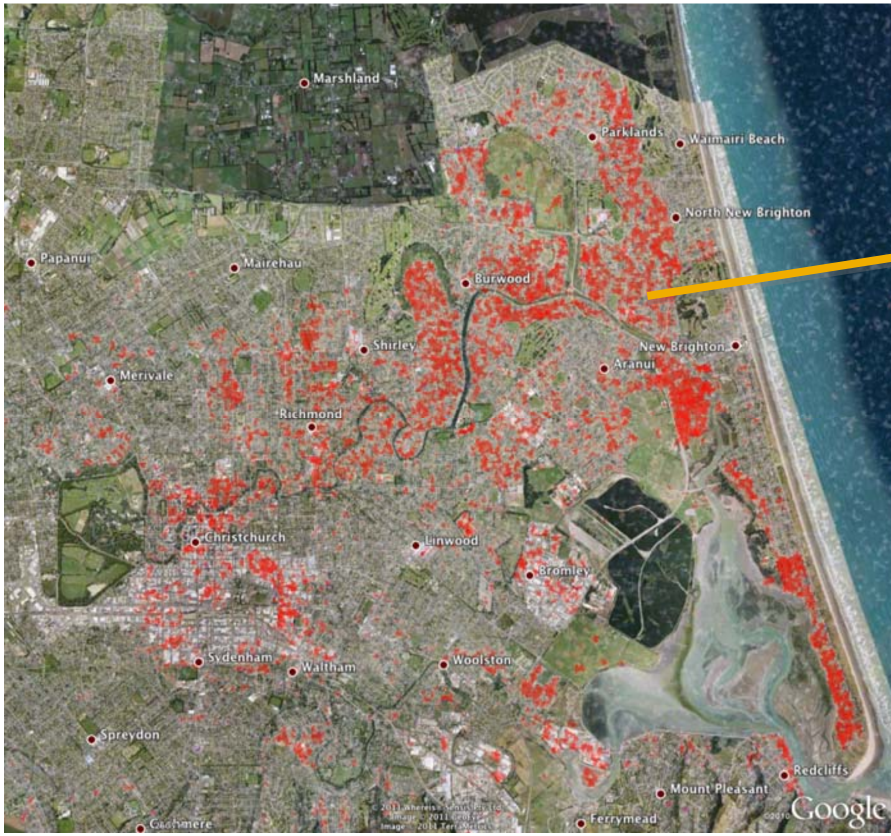


Damage Proxy Map (ALOS PALSAR A335):
2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth (GeoEye) Image: 2011/02/26



2011/06/22 version
Sourced from geospatial.govt.nz, Created by Tonkin & Taylor NZ for CERA (Christhurch Earthquake Recovery Authority)

Caveat: Not Necessarily Land Surface Change

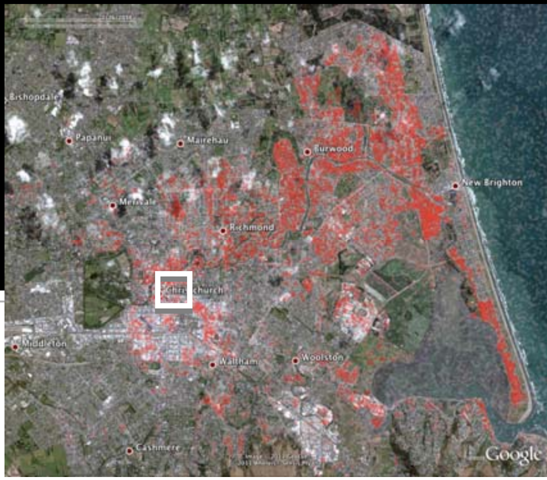


Damage Proxy Map (ALOS PALSAR A335):
2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth (GeoEye) Image: 2011/02/26

Image from koordinates.com

Christchurch Cathedral

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye



Christchurch Cathedral on the day of the earthquake (REX/The Telegraph)

Damage Proxy Map

2010/09/03

2011/02/23

Cathedral of the Blessed Sacrament

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

Cathedral of the Blessed Sacrament was partly collapsed. (David Wethey/NZPA/Associated Press)

Damage Proxy Map

2010/09/03

2011/02/23

Canterbury TV Building

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

Rescuers working throughout the night at the Canterbury TV building where up to 100 people are feared lost as they look to recover bodies rather than rescue survivors. (www.news.com.au)

Damage Proxy Map

2010/09/03

2011/02/26

Pyne Gould Building

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

The collapsed Pyne Gould Guinness building trapped dozens of people. “We’ve been pulling 20 or 30 people out of those buildings right throughout the night,” police Superintendent Russell Gibson said Wednesday morning. (Mark Mitchell/AFP/Getty Images)

Damage Proxy Map
building damage + liquefaction

2009/03/04

2011/02/26

Cliff Collapse

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

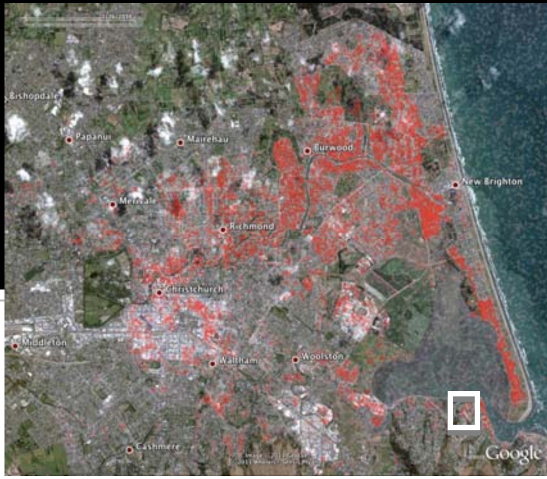


Photo Courtesy David Petley

Luxury homes teeter on the edge after huge landslides in Redcliffs, near Christchurch (Photo by Torsten Blackwood from AFP).

Damage Proxy Map

2010/09/03

EQ M6.3

2011/02/23

2011/02/26

Liquefaction near Bridge Street

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

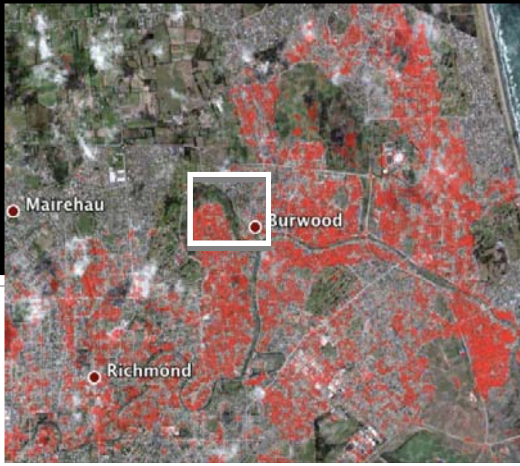
Damage Proxy Map

2010/09/03

2011/02/23

Liquefaction near Burwood

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye



Damage Proxy Map

2009/03/04

EQ M6.3

2011/02/22

2011/02/23

2011/02/26

Severe Liquefaction in Bexley

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

Cars stuck in the mud, Bexley
(Brett Phibbs/AFP/Getty Images)

Water Inundated Bexley (Mark Mitchell/New Zealand Herald/Associated Press)

Damage Proxy Map

2009/03/04

2011/02/23

Conclusions

- Future radar satellites will visit us within a day after an event. The expected wait time for the first SAR satellite to visit Lat: 38°N after a major earthquake in 2018 is 8~15 hours. Data transfer latency that often involves human/agency intervention far exceeds the data acquisition latency. → Need interagency cooperation to automate and accelerate the data transfer.
- We developed a prototype damage proxy map algorithm that uses interferometric coherence to generate damage proxy maps, to improve situational awareness for rescue operations and disaster size estimation after a major natural disasters.
- The algorithm was tested with ALOS PALSAR data of downtown Pasadena, California, and produced encouraging results. We are working on quality assessment, trying to estimate the probability of detection and probability of false alarm of the algorithm on the test area.
- Application to Feb. 2011 M6.3 Christchurch Earthquake detected three types of damage: liquefaction, building, cliff collapse. The overall damage pattern agrees well with ground truth map, and building scale damage sites were confirmed with optical imagery.
- The algorithm will be improved utilizing temporal characteristics of coherence and optimized for each type of data (L/C/X-band, Envisat, TerraSAR-X, COSMO-SkyMed, UAVSAR, DESDynI).