Software System Products

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Integrating Space Geodesy Seismology Modeling

Examples from the 2011 M9.0 Tohoku-Oki (Japan) earthquake

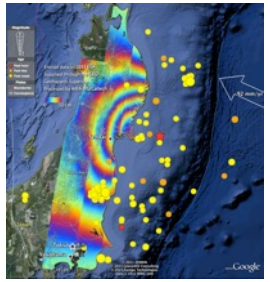
Radar Sensors

GPS Networks

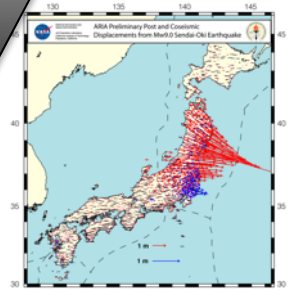
Seismic Networks

Optical Sensors

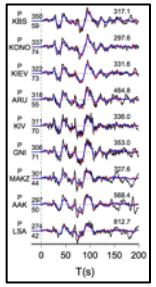
Automated Data Collection & Processing



Radar



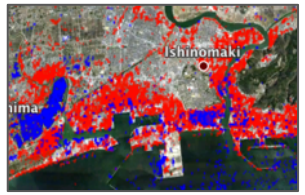
GPS



Seismology

Monitoring & Near Real-Time Assessment

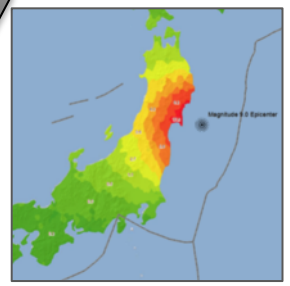
Potential Partners



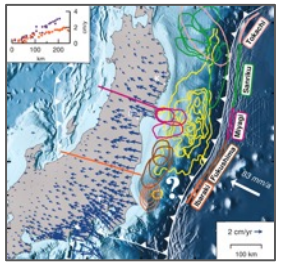
Building Damage & Inundation

"This is exactly the kind of product we are looking for."

Anne Rosinski
Calif. Geol. Survey



Permanent Ground Deformation



High-Resolution Hazard Assessment from Fault Models

"We have high hopes for ARIA."

Keiko Saito
World Bank

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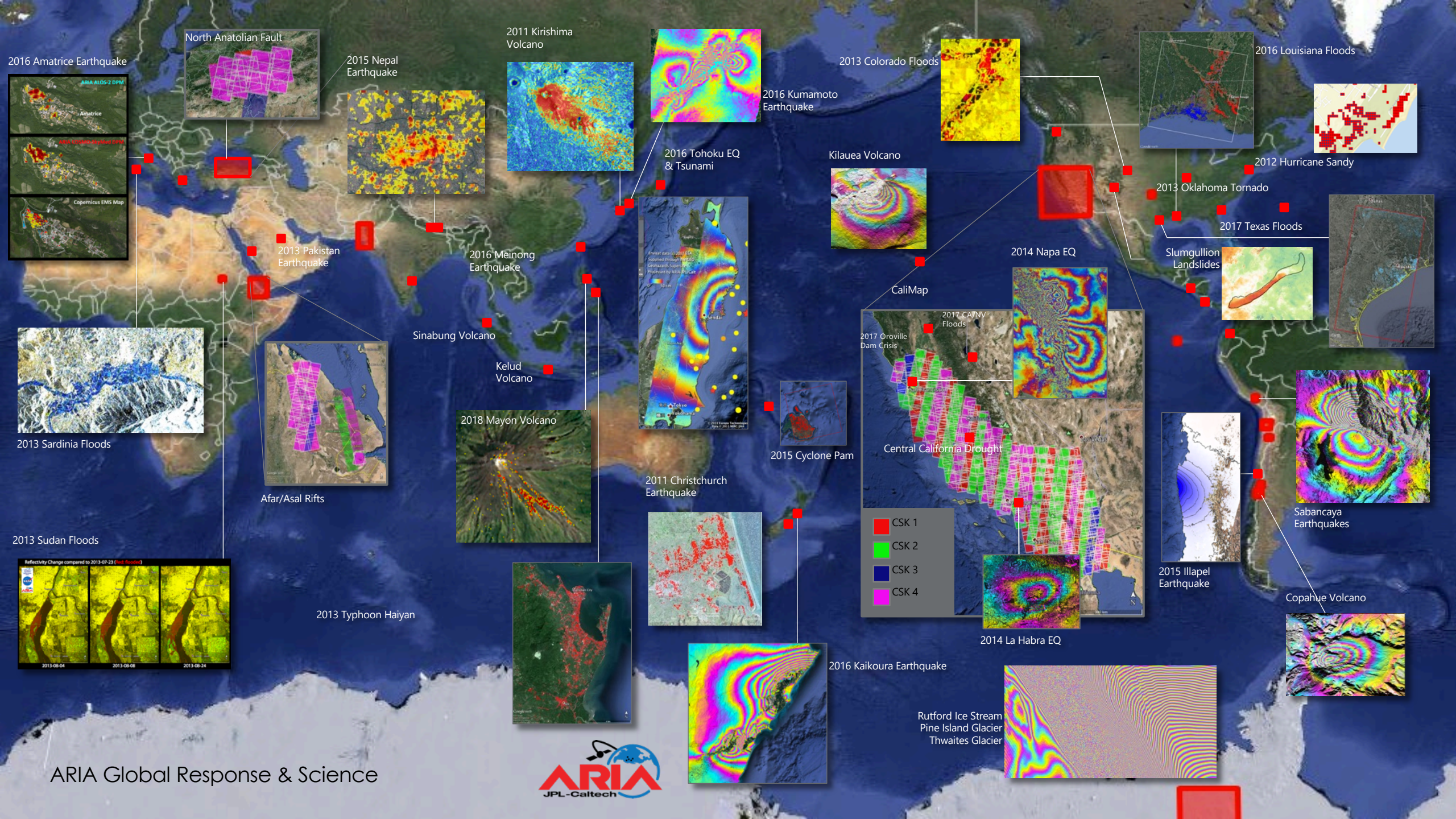
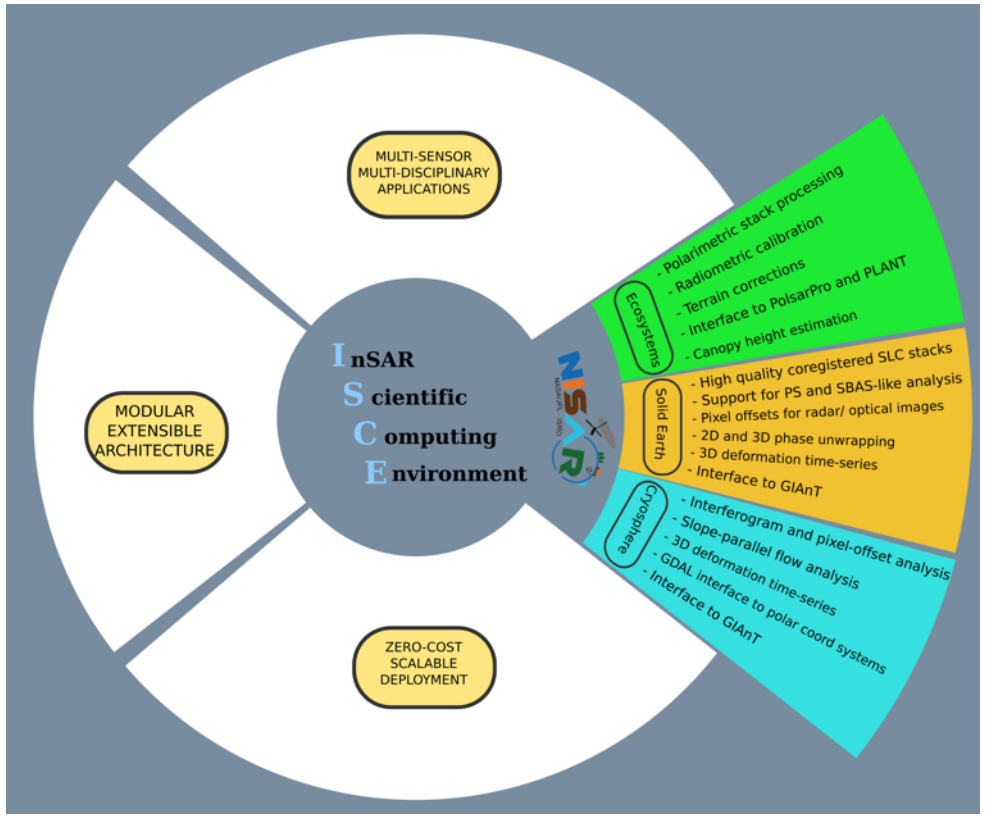

2016 Amatrice Earthquake
ARIA ALOS-2 DPM
Amatrice
Copernicus EMS Map
North Anatolian Fault
2015 Nepal Earthquake
2011 Kirishima Volcano
2016 Kumamoto Earthquake
2013 Colorado Floods
2016 Louisiana Floods
2012 Hurricane Sandy
2016 Tohoku EQ & Tsunami
Kilauea Volcano
2013 Oklahoma Tornado
2017 Texas Floods
2013 Pakistan Earthquake
2016 Meinong Earthquake
2014 Napa EQ
Slumgullion Landslides
CaliMap
2017 CA/NV Floods
2017 Oroville Dam Crisis
Sinabung Volcano
Kelud Volcano
2013 Sardinia Floods
2018 Mayon Volcano
2015 Cyclone Pam
Central California Drought
Afar/Asal Rifts
2011 Christchurch Earthquake
CSK 1
CSK 2
CSK 3
CSK 4
Sabancaya Earthquakes
2015 Illapel Earthquake
2013 Sudan Floods
Reflectivity Change compared to 2013-07-23 (red: flooded)
2013-08-04
2013-08-08
2013-08-24
2013 Typhoon Haiyan
2014 La Habra EQ
Copahue Volcano
2016 Kaikoura Earthquake
Rutford Ice Stream
Pine Island Glacier
Thwaites Glacier
ARIA Global Response & Science
ARIA
JPL-Caltech

ISCE: A modular, reusable library for scalable SAR/InSAR processing



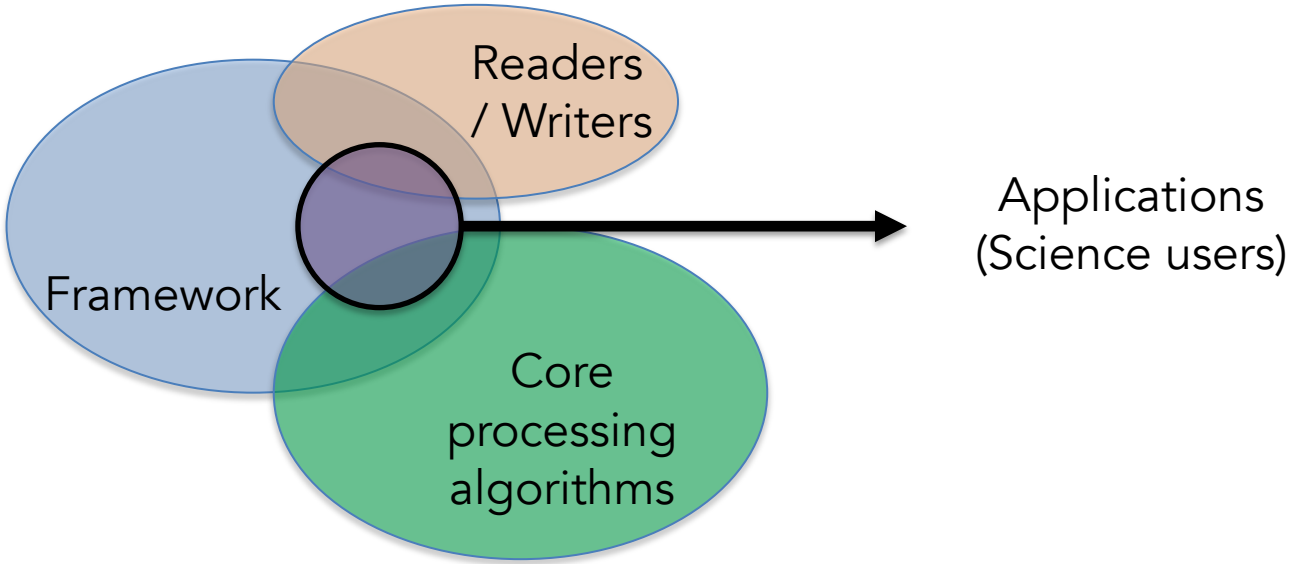
ISCE Team (JPL/Caltech/Stanford)

What is ISCE?

- InSAR Scientific Computing Environment

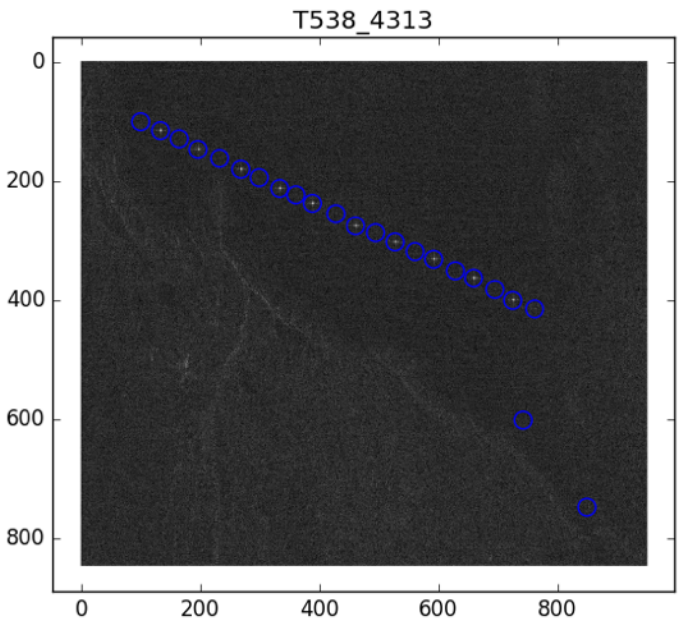
- Processing framework for SAR / InSAR data
  - C/C++/Fortran core for performance
  - Python interface for user scripting and testing

- Applications / workflows built on top of the same set of building blocks
  - Reuse capability as much as possible
  - Easy incorporation of new sensors / imaging modes

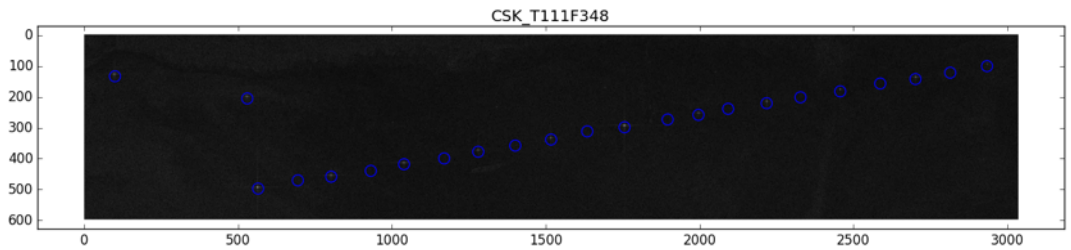


Core SAR/InSAR Processing Capabilities

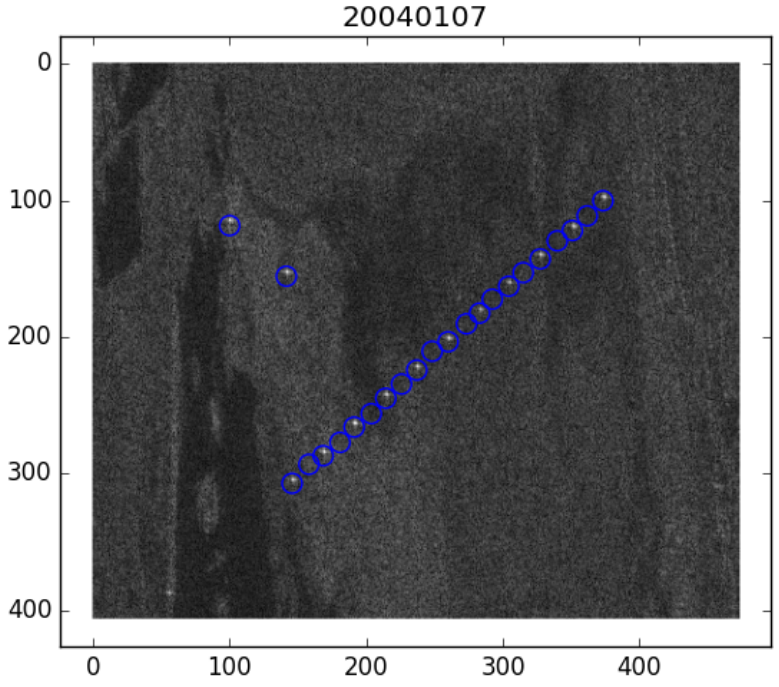
SAR – Focusing and Geometry



ALOS PALSAR – near zero doppler



COSMO SkyMed – near zero doppler

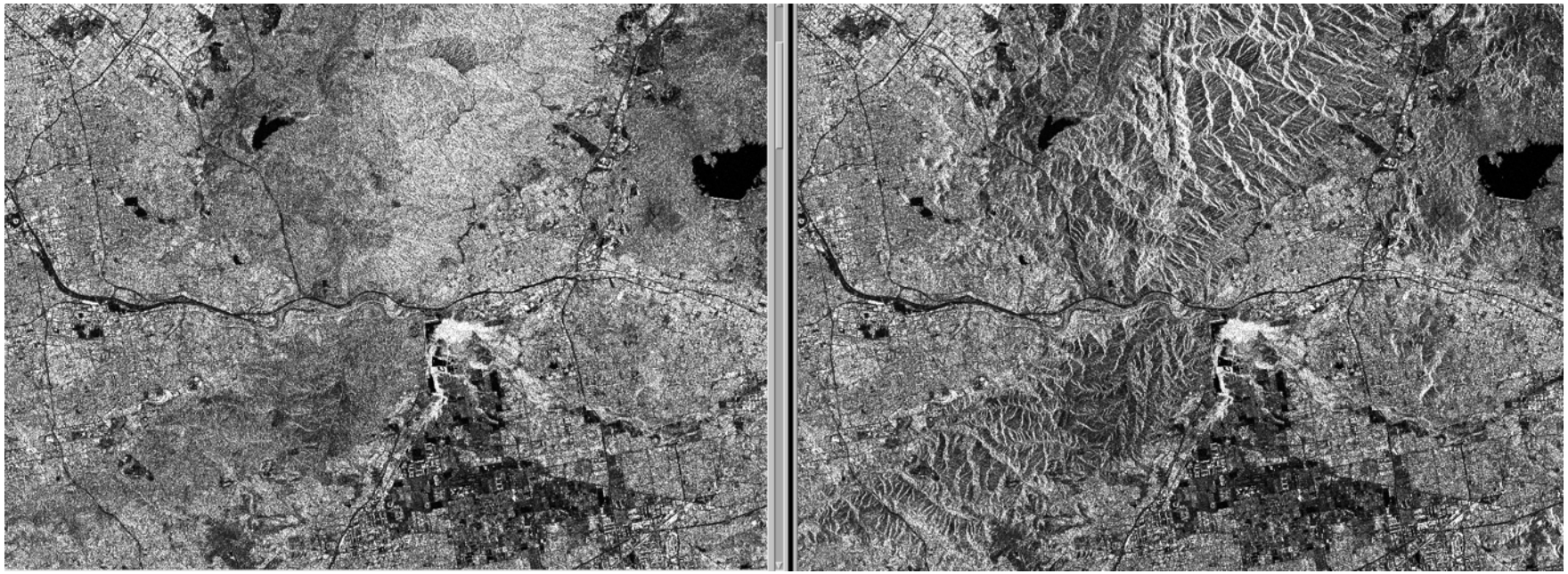


ERS2 - Ambiguity of -4

- Mroipac.formslc is pretty robust
- Needs updates to handle higher resolution datasets
  - Stop-and-go approximation
  - Secondary Range Migration

SAR – Radiometric Terrain Correction / Simulation

Using S1B GRD data



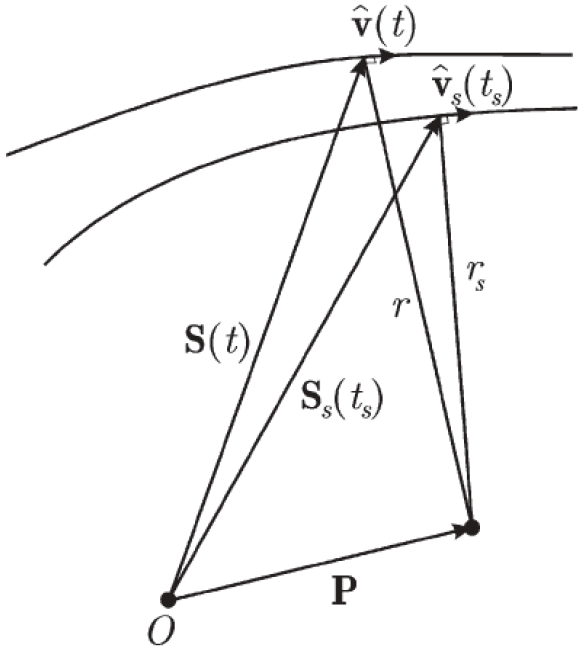
Gamma0 Beta0

- Simple band math with output of isce.zerodop.topozero
  - Shadow Layover mask
  - Local incidence angle
  - Projection angle
  - Lat, Lon, Hgt

Geometric Image Coregistration

Slide modified from: Fattahi et al (2016)

- Exploit precise orbit information
- Geometry system is important
- Residual constant offsets
  - Azimuth clock errors
  - Slant range bulk media shift
- Most modern SAR sensors provide high quality orbit information
- Metadata quality has significantly improved over last decade

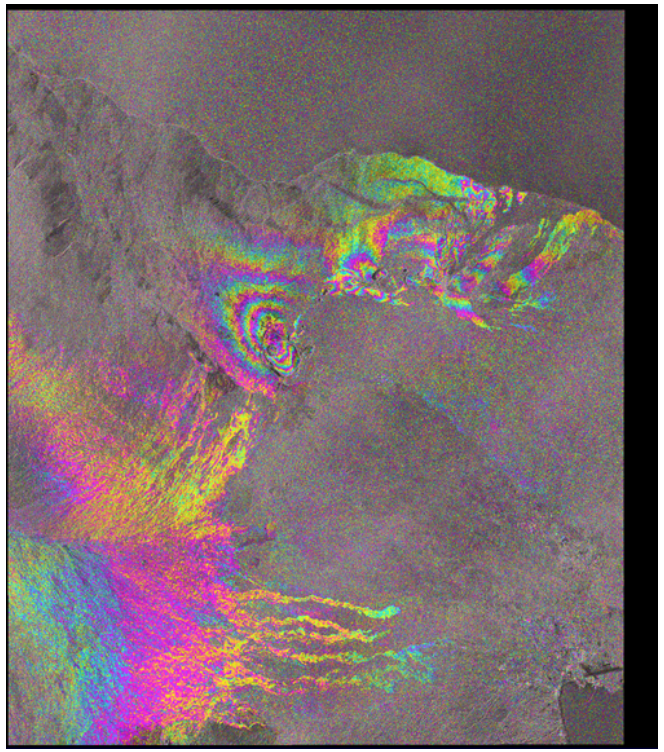


Master Azimuth Time, Slant Range $\xleftrightarrow[\text{\& DEM (rdr2geo)}]{\text{Using Orbit}}$ Lat, Lon, Ht On ground $\xleftrightarrow[\text{(geo2rdr)}]{\text{Using Orbit}}$ Slave Azimuth Time, Slant Range

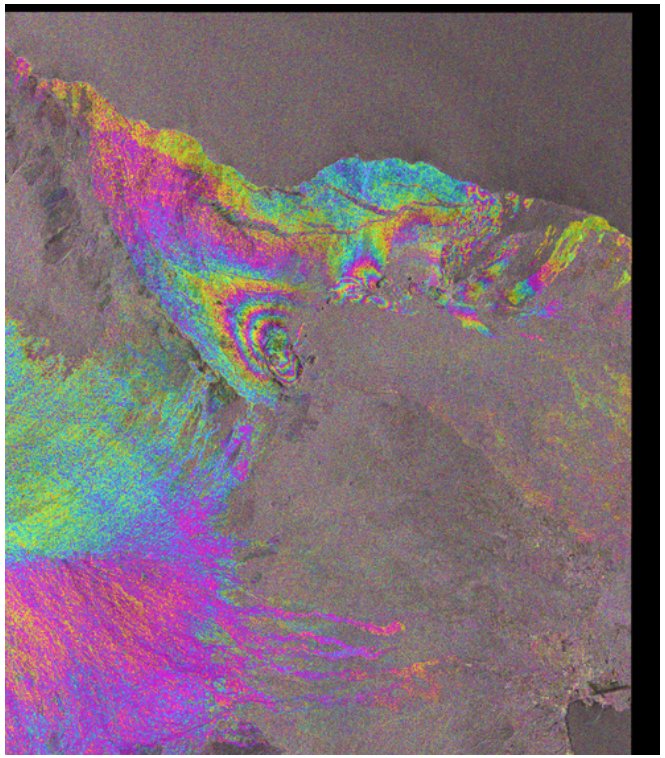
Needs precise Orbits (few cm).

Doesn't Need Accurate DEM (few 10s of m vertical acc is fine).

Comparing co-registration methods



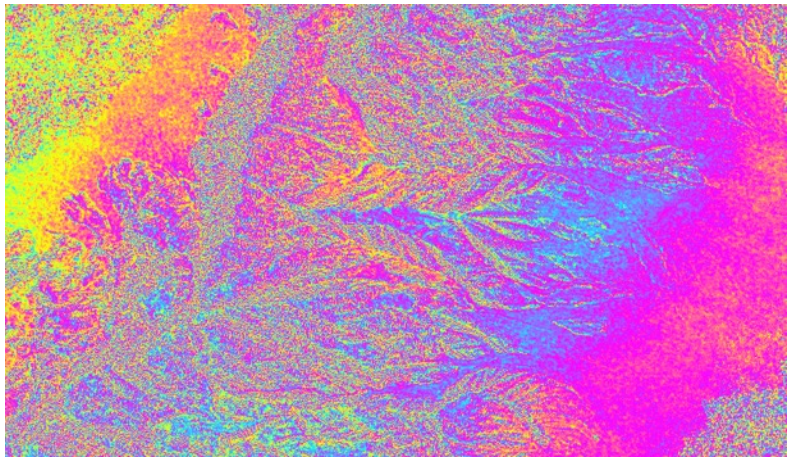
Traditional polynomial based coregistration



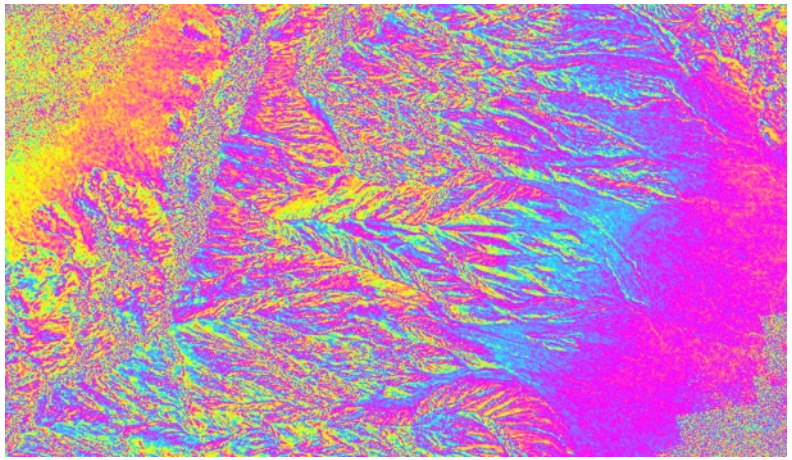
Geometric coregistration

4 year, 4km baseline ALOS PALSAR dataset over Hawaii

Comparing coregistration methods



Polynomial-based



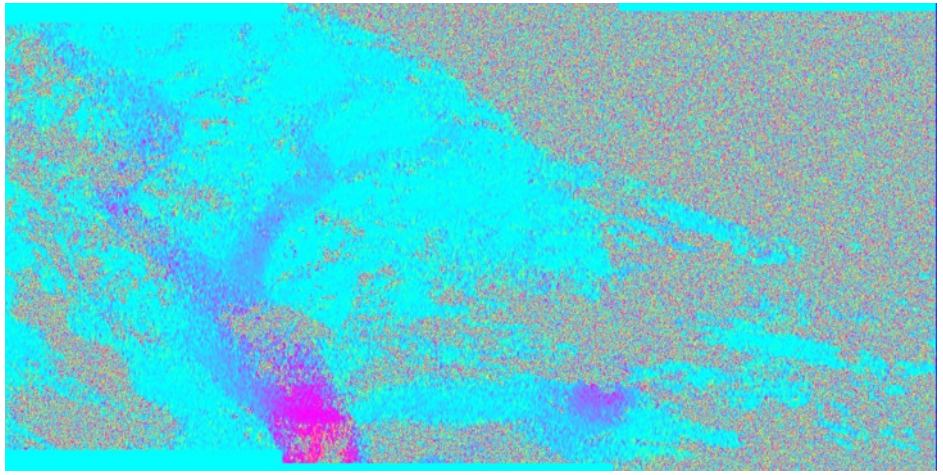
Geometry-based

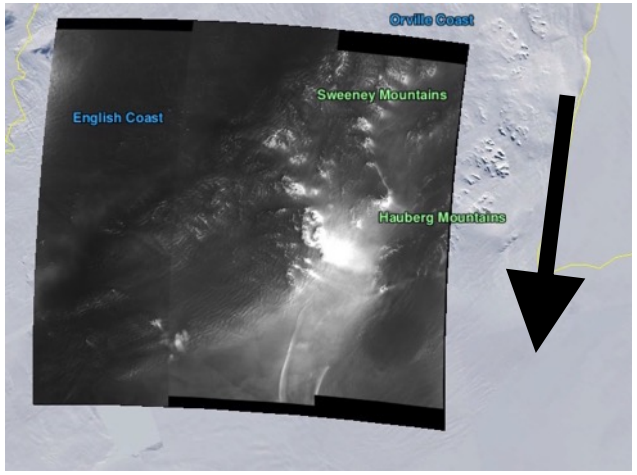
2km baseline ALOS PALSAR dataset over Eastern California

- Geometric co-registration performs better over steep terrain
- Geometric co-registration works better for wider range of baselines
    - Better alignment of pixels in stacks of radar images
- Hard to meet Sentinel-1 TOPS InSAR requirements with traditional co-registration methods

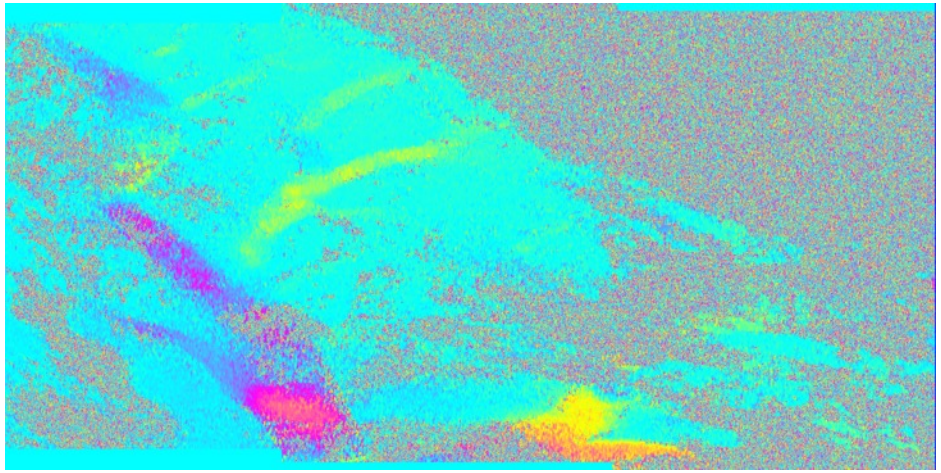
Speckle tracking – pixel offsets

Azimuth offsets





-1 +1

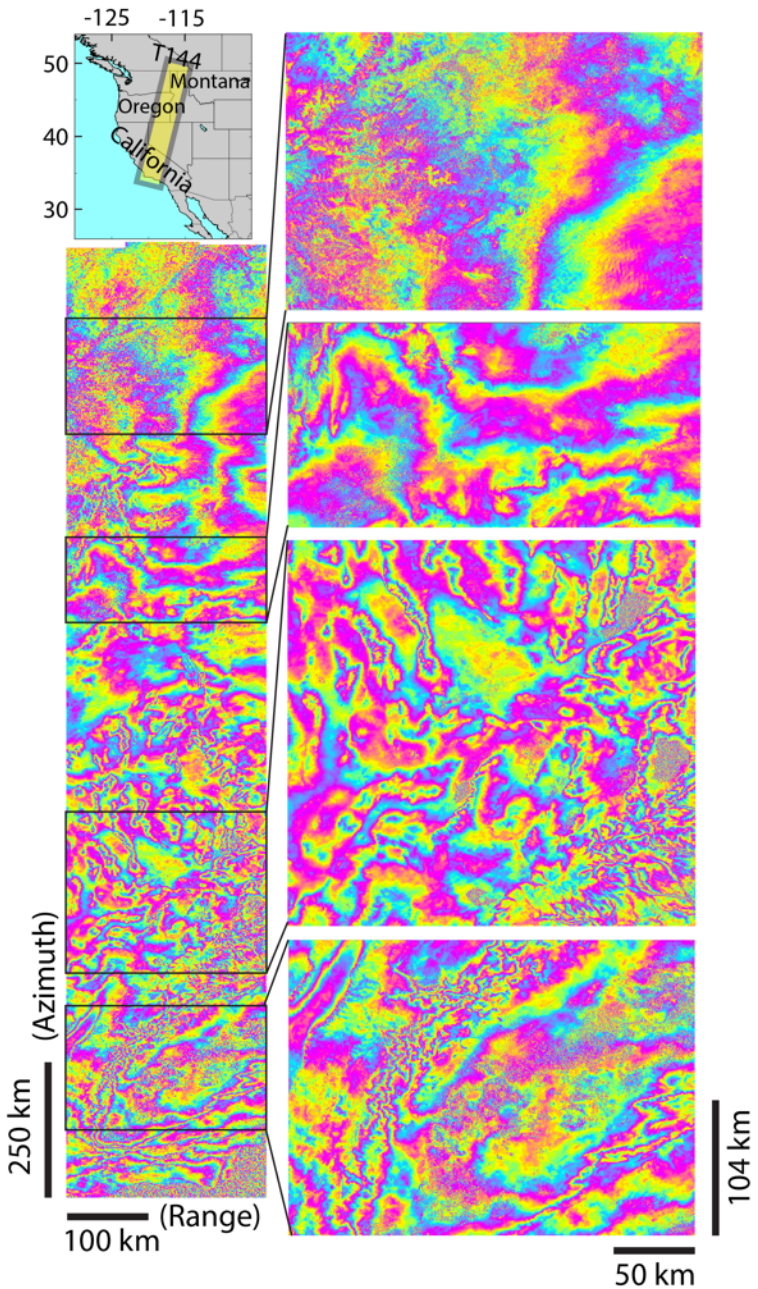


Range offsets

- GPU implementation in the works
- Geometric co-registration reduces complexity

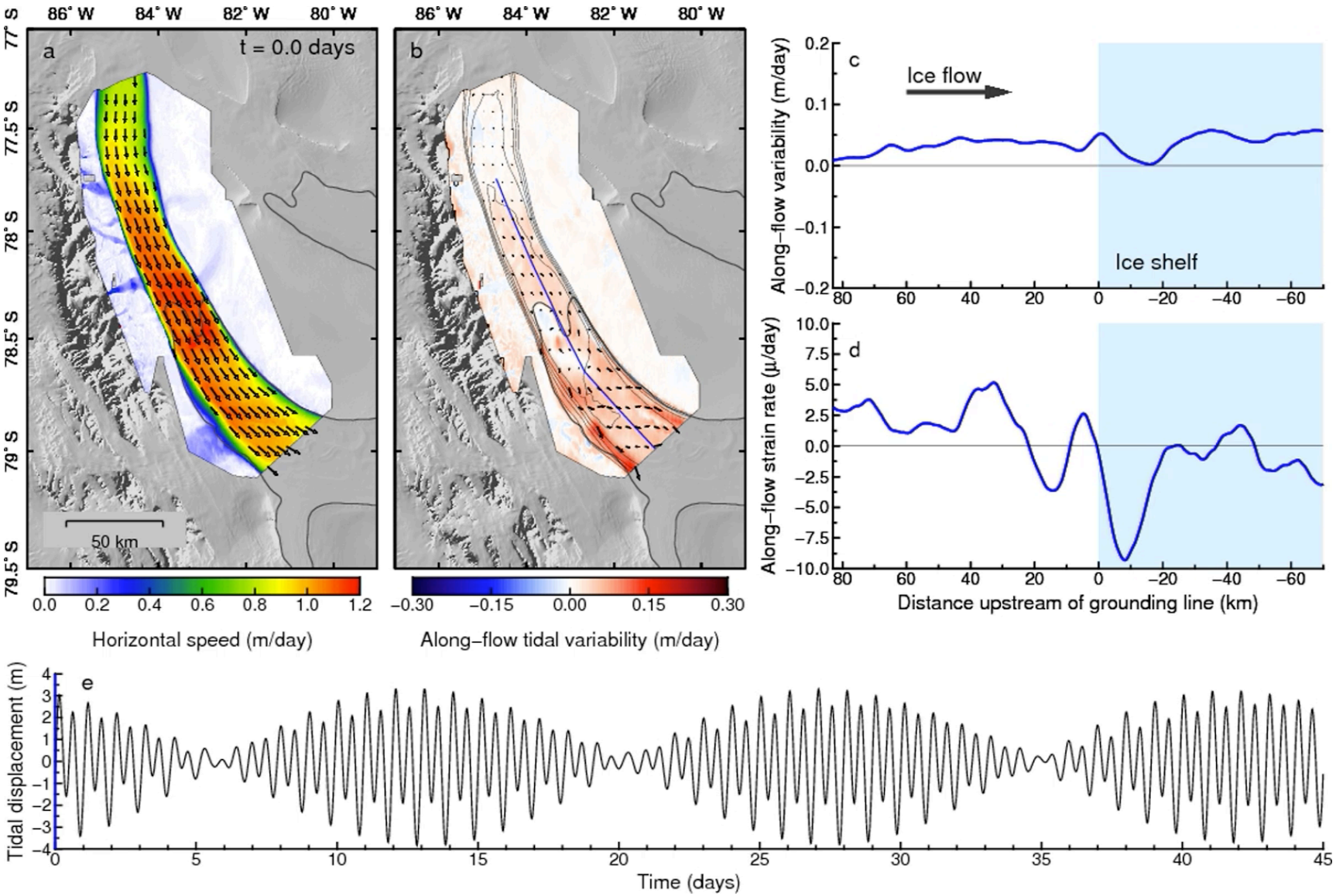
ISCE in action
Real-life examples from advanced users

Sentinel-1 TOPS interferometry (Fattahi et al)

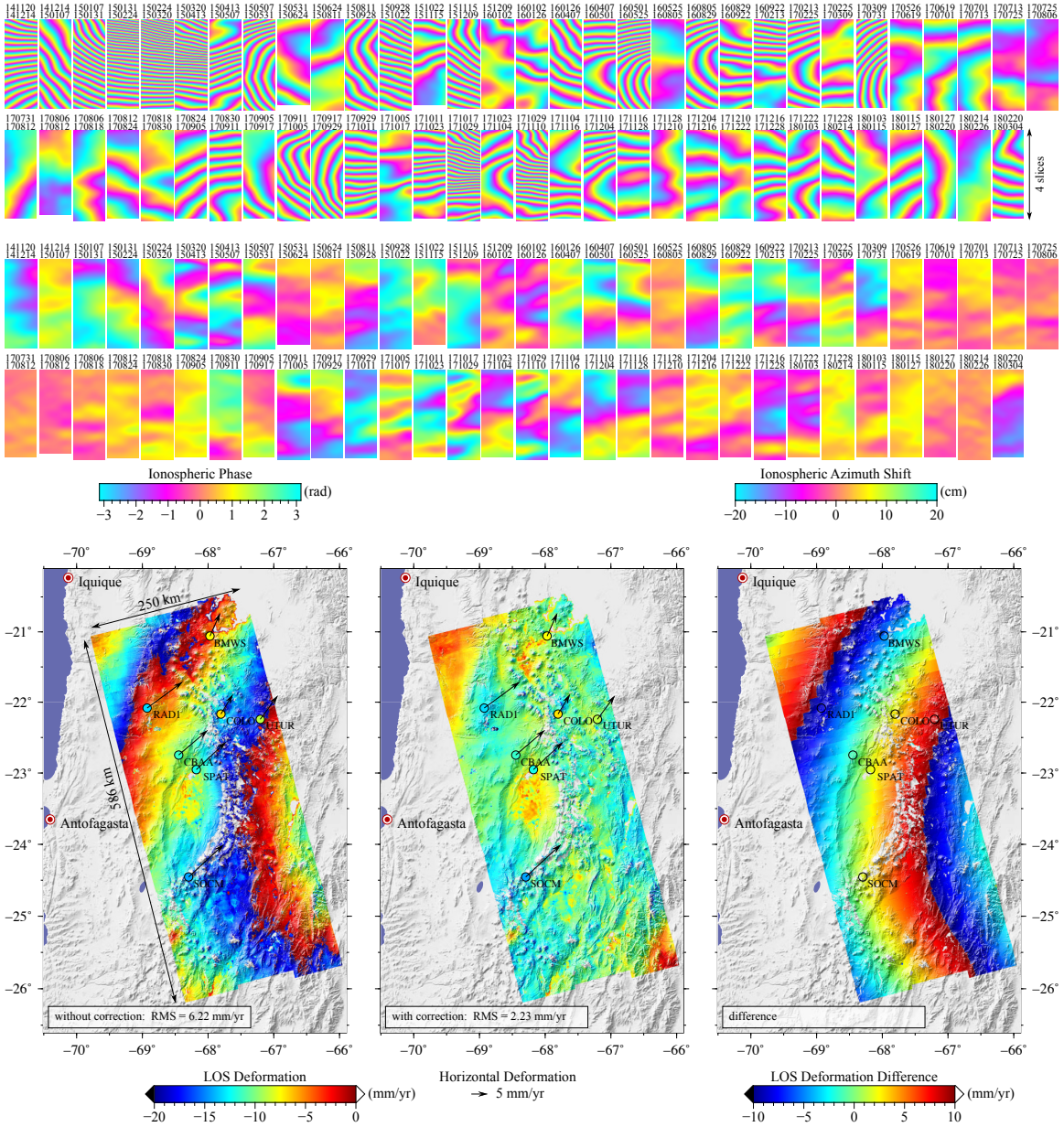


- Geometry-based processing allows us to stitch numerous frames of SLCs seamlessly
  - Good to about 1/100 th of pixel
- Sentinel-1 azimuth mis-registration refinement implemented using burst overlaps
  - Good to about 1/1000 th of pixel

3D pixel offset time-series (Minchew et al.)

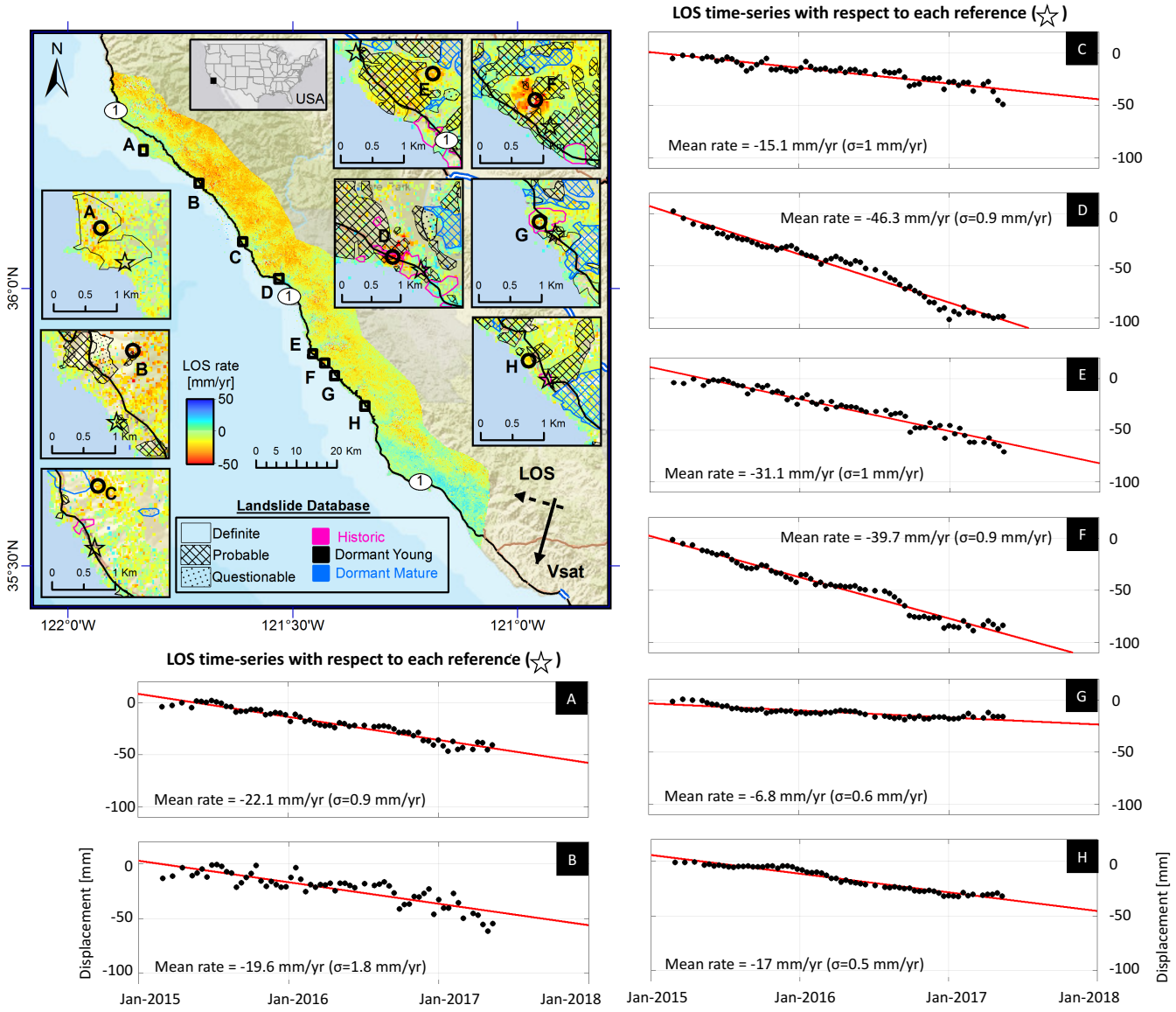


Ionospheric corrections for Sentinel-1 (Liang et al., in reivew)



- Slightly different approach due to bursty nature of data
- Ionosphere is estimated at an assumed height and reprojected back on ground

Infrastructure monitoring (Bekaert et al)



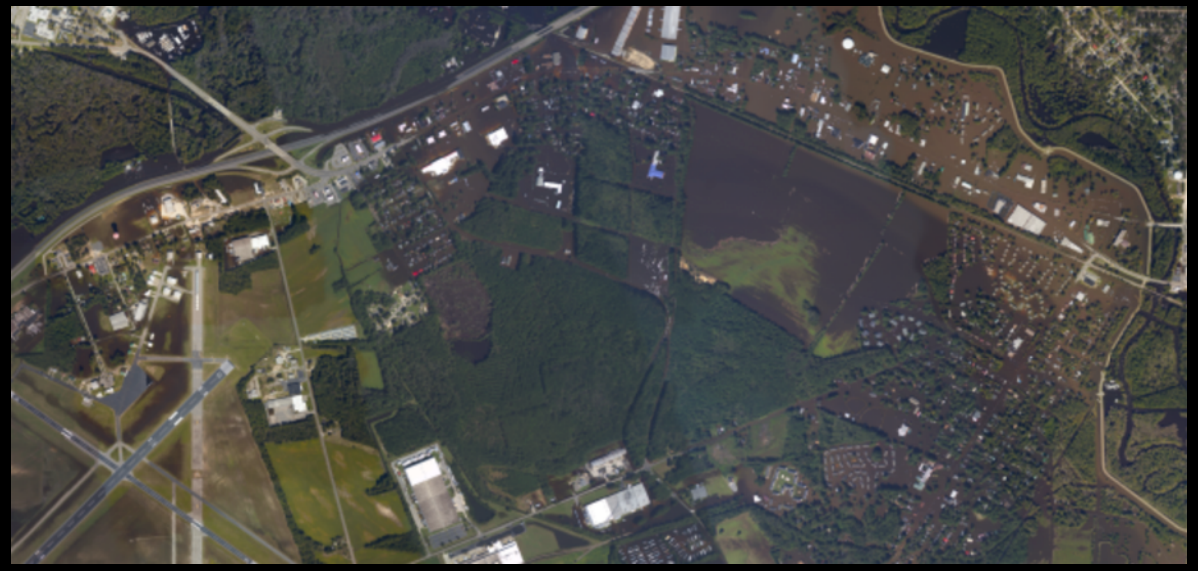
Coregistration is the critical driver for analysis of stacks with large baseline spans and for high resolution analysis

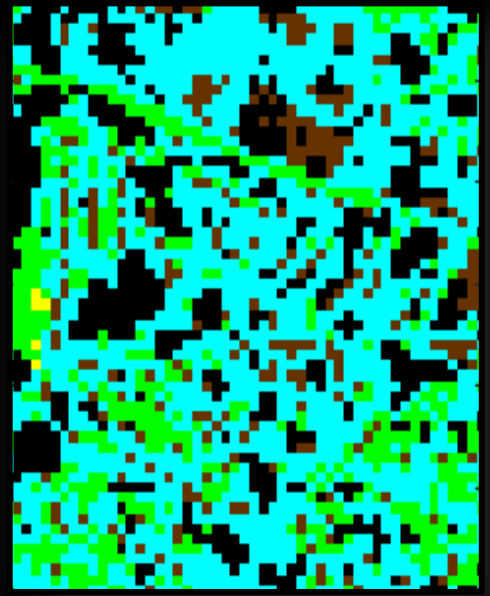
Jet Propulsion Laboratory
California Institute of Technology

D. Bekaert, P. Agram, and H. Fattahi.
The research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. ArcGIS 10.4 software (http://www.esri.com/software/arcgis) was used to generate the overview figure. Service layer credits ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User community. Landslide catalogue contributed by the California Department of Conservation. Contains modified Copernicus Sentinel data (2017), processed by D. Bekaert, P. Agram, and H. Fattahi. © 2017 California Institute of Technology. Government sponsorship acknowledged.

Rapid Flood and Damage Mapping

2016 Hurricane Matthew, Lumberton, North Carolina (Lin et al., in prep)





- Open water mapping straightforward
- Urban flood mapping is challenging
- Multitemporal SAR analysis produced sensitivity by 85%
- Deep learning is being explored

185 people killed

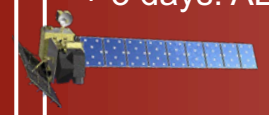
Over 1000 buildings destroyed

US $30+ billion damage

Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct

M6.3
Chch EQ

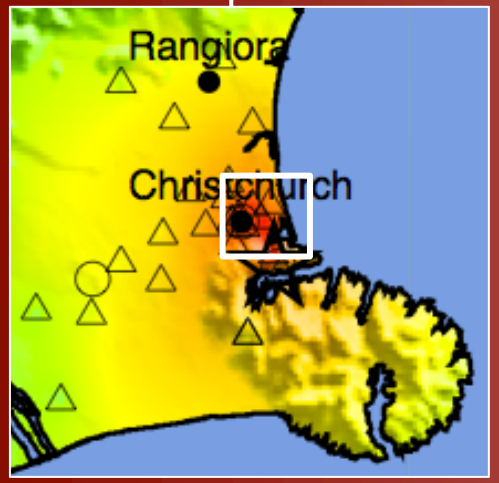
+ 3 days: ALOS acquires data



+ 4 months

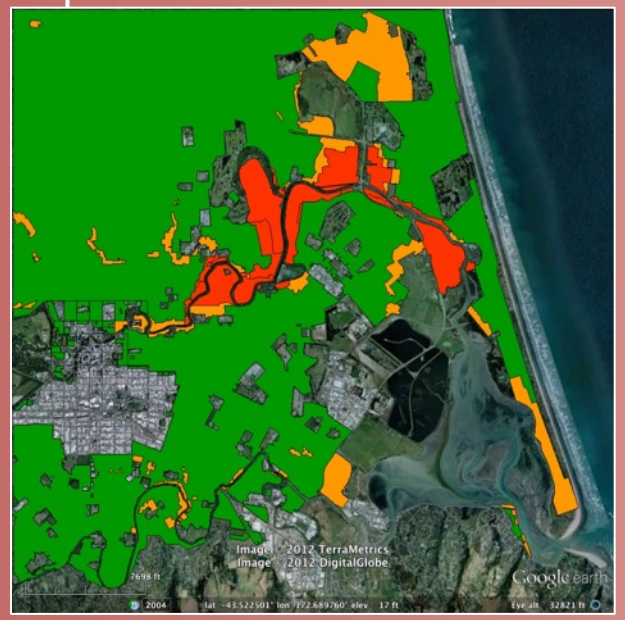
+ 8 months

+ 20 min



Multiple versions of Shakemap released
(USGS NEIC)

DPM from PALSAR data
(ARIA)



Official damage map
released based on
ground observations
(NZ Government)

Official damage map
updated based on
ground observations
(NZ Government)

Feb 2011 Christchurch Earthquake

Economic Loss

Feb 2011 Christchurch Earthquake

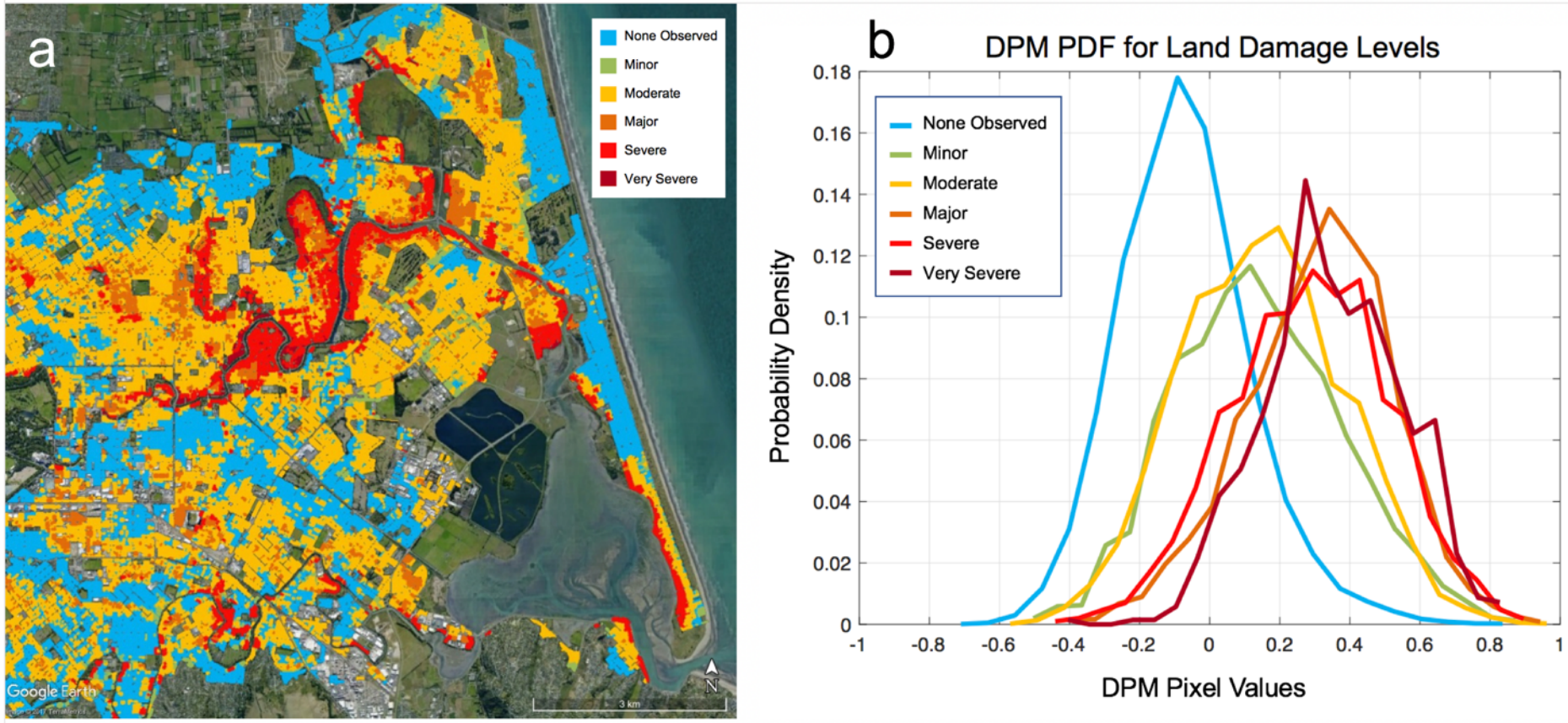
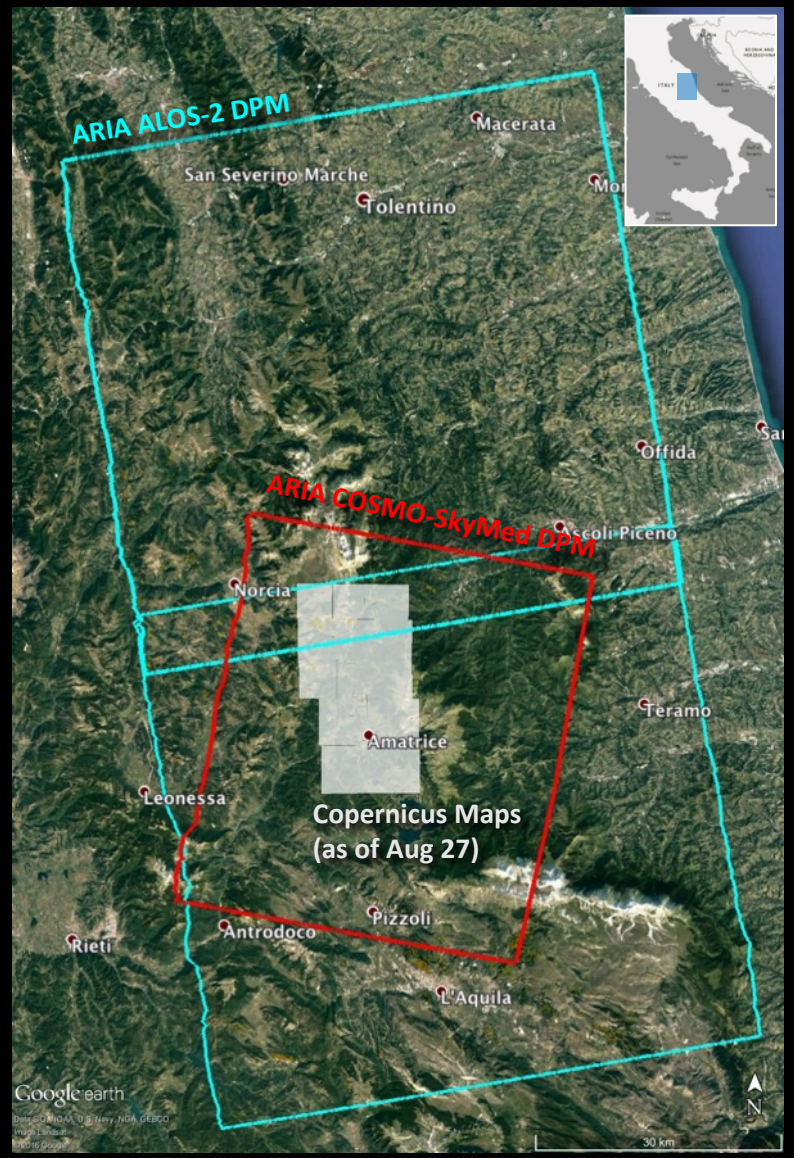
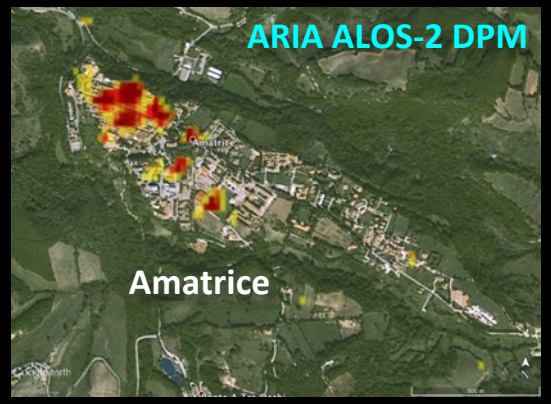
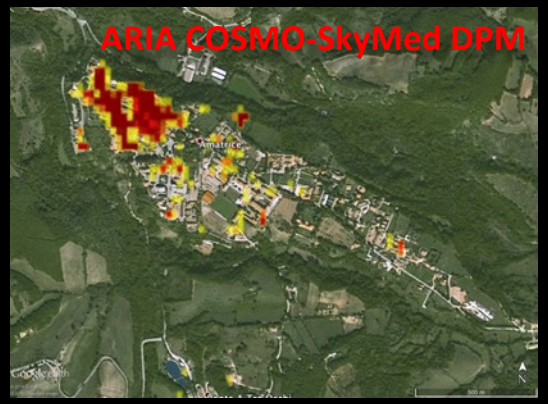


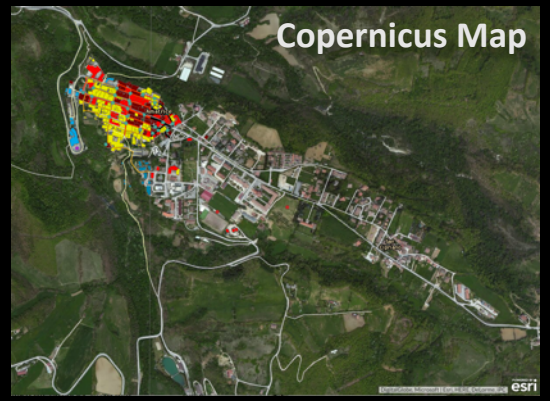
Figure 11. a) Land damage map, b) Histogram of the DPM for each level of the land damage.

Amatrice Earthquake (M6.2 Aug 24, 2016), Italy







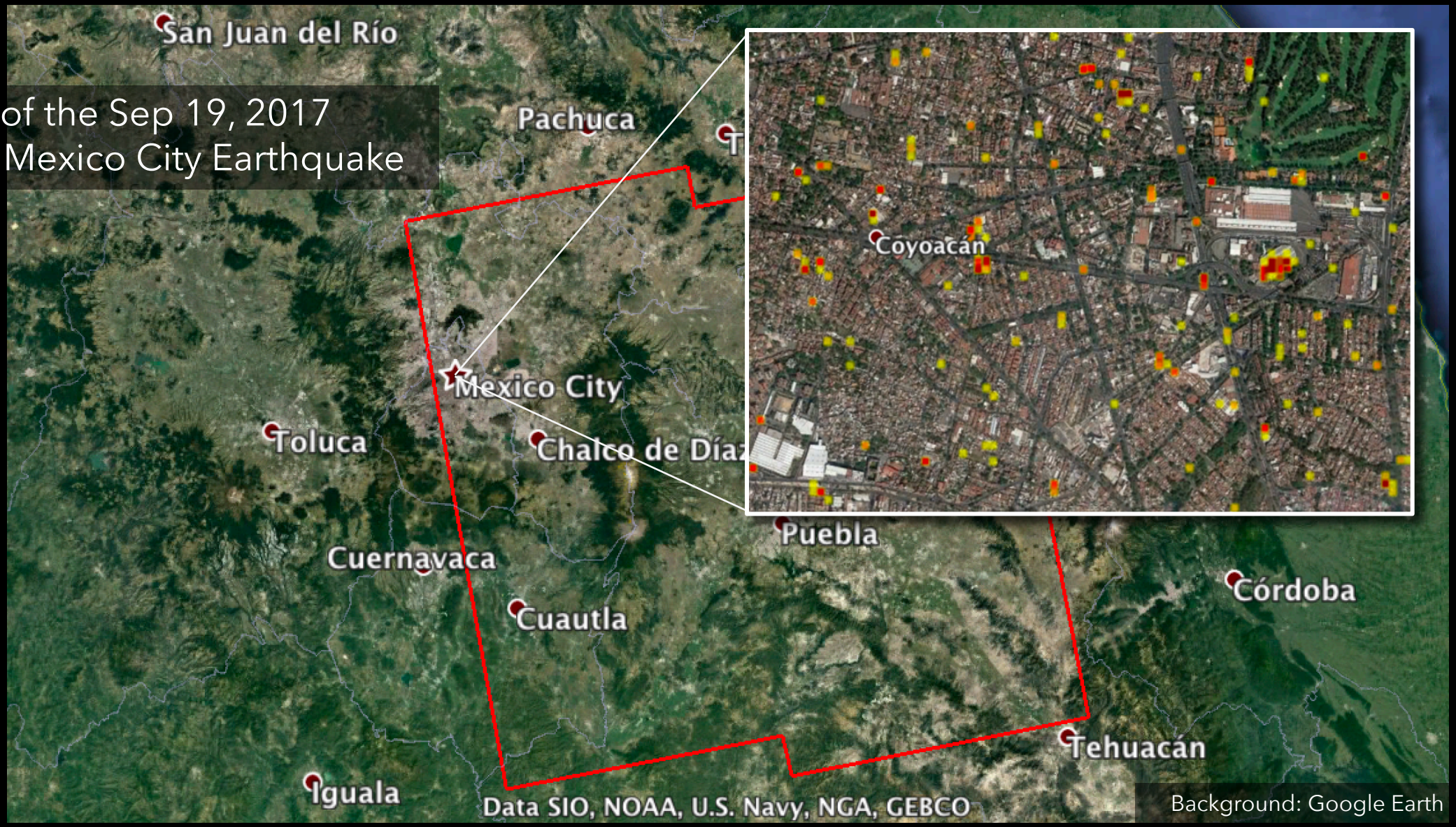


Gregorio Borgia (Associated Press)
https://www.nytimes.com/interactive/2016/08/24/world/europe/italy-earthquake-before-after-amatrice-accumoli.html

Corso Umberto (Reuters)
http://temblor.net/earthquake-insights/nasa-radar-maps-reveal-massive-extent-of-amatrice-damage-from-italy-earthquake-1271/

https://www.nasa.gov/feature/jpl/nasa-produced-maps-help-gauge-italy-earthquake-damage

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



Background: Google Earth

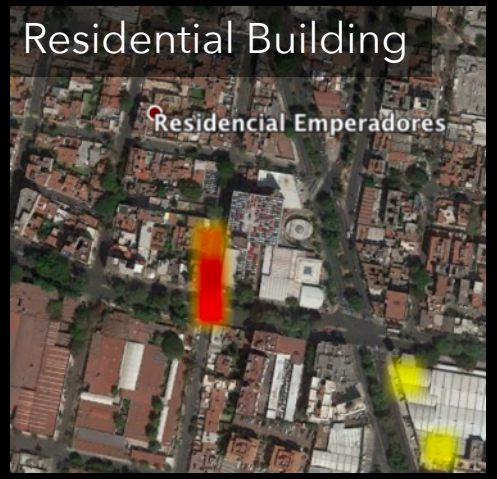
https://www.nasa.gov/feature/jpl/nasa-produced-damage-maps-may-aid-mexico-quake-response

DPM vs Ground Observation (M7.1 Mexico City Earthquake)

DPM

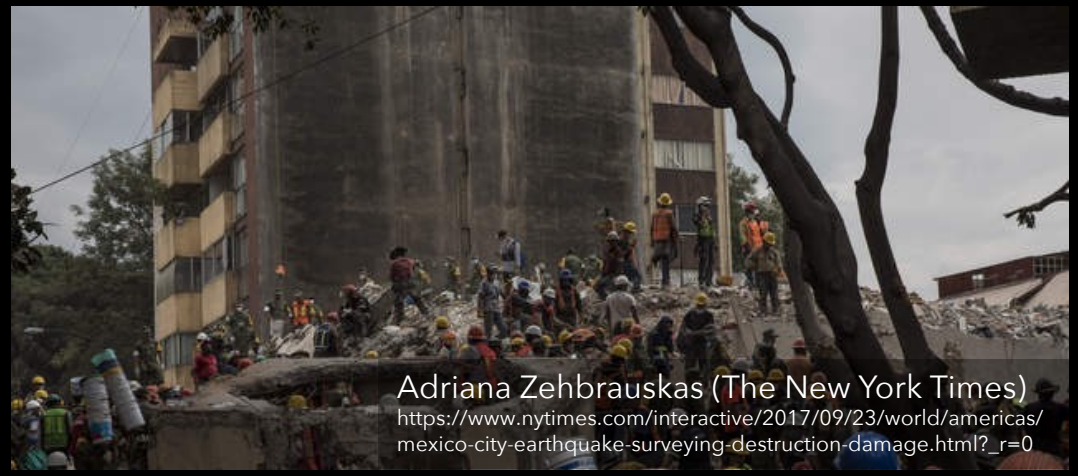
Before

After



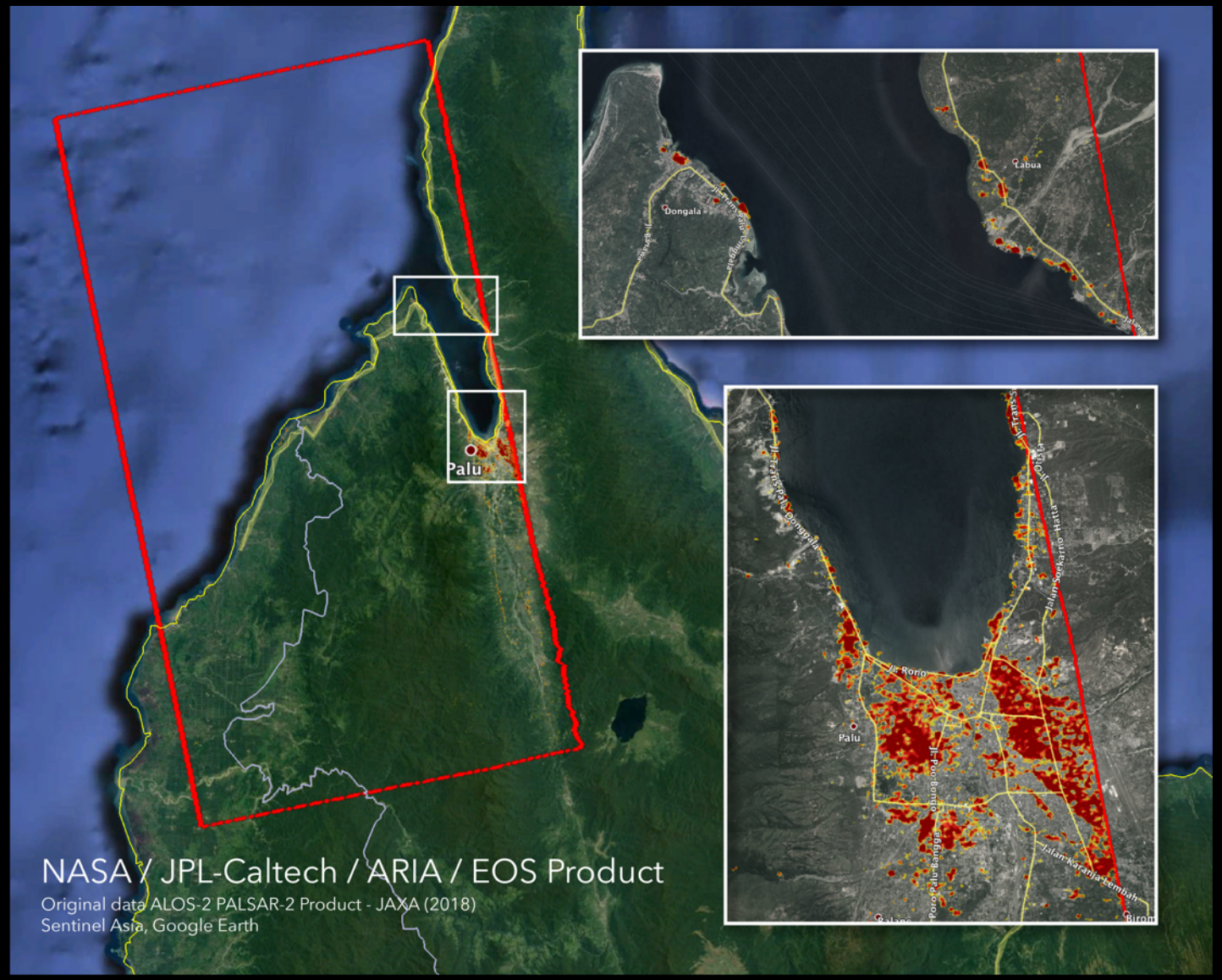
DPM

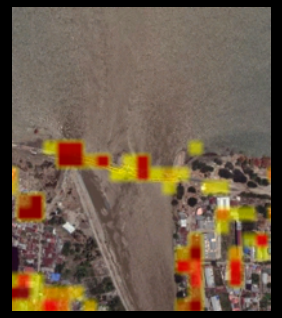
Before

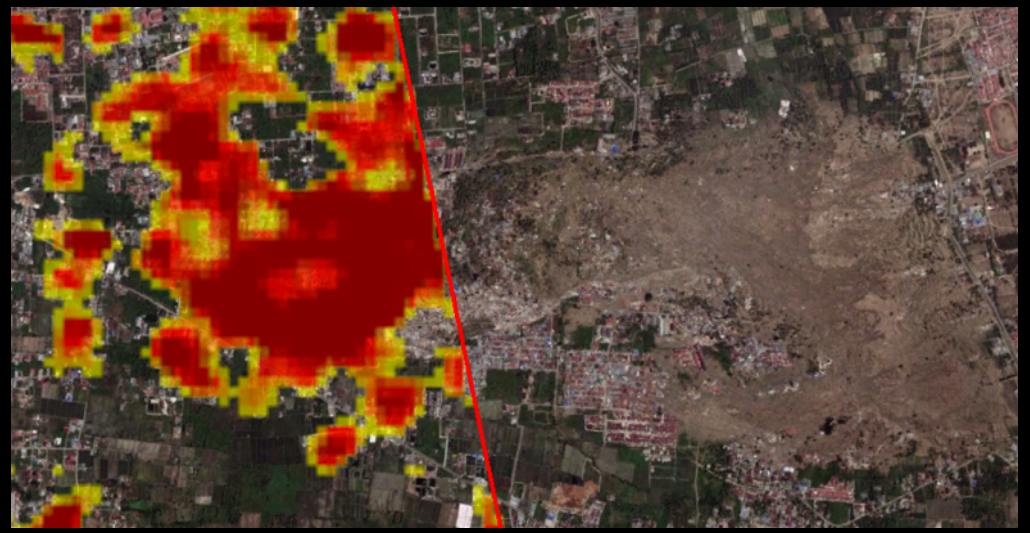


After

September 2018 M7.5 Palu Earthquake, Indonesia

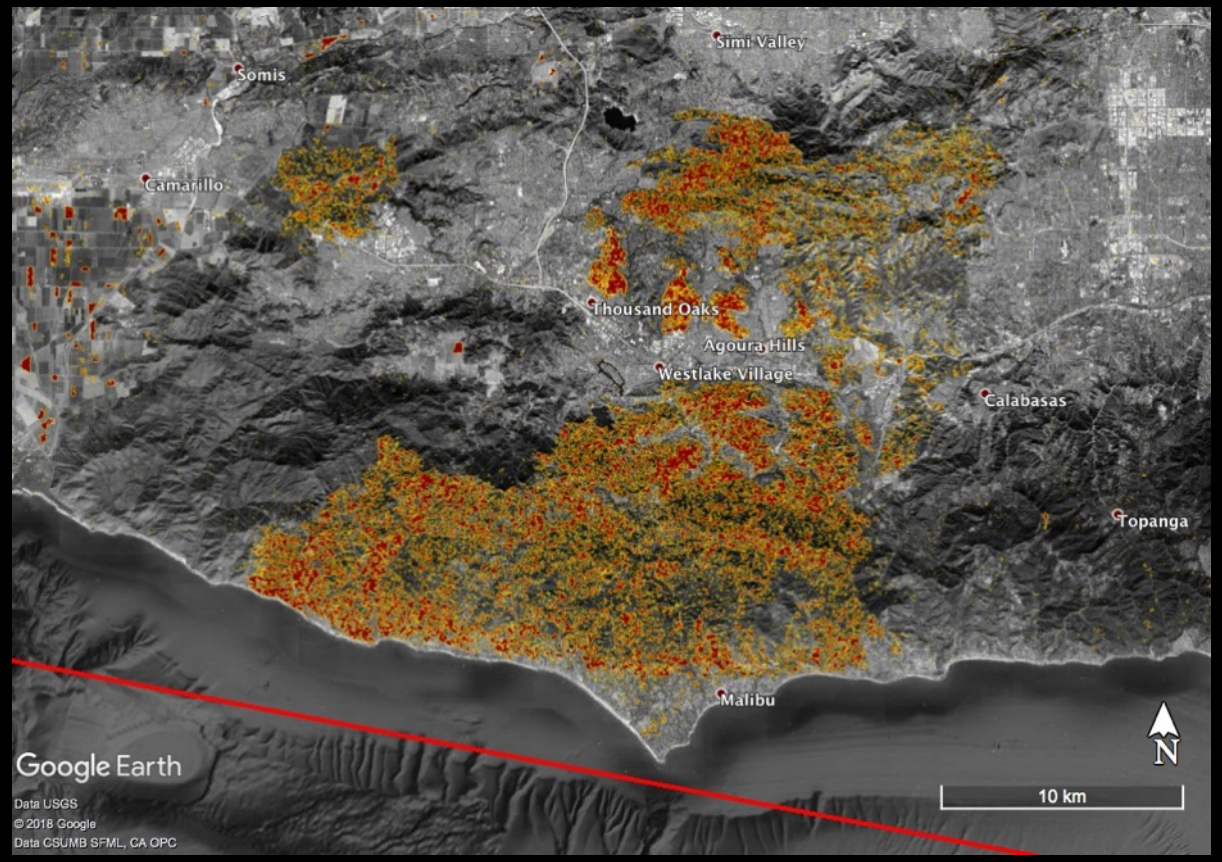






Woolsey Fire, Southern California (November 2018)

ARIA DPM from Sentinel-1



2018-11-11 6:00 AM

False Color Image (Planet)

2018-11-11 10:30 AM

https://www.nasa.gov/feature/jpl/nasas-aria-maps-california-wildfires-from-space

"We estimated that Louisiana would have about 27,000 damaged homes, but it was through the acquisition of SAR data and other remotely sensed data that we were able to see that it was a much larger impact than we had forecast."

Glenn Russell, FEMA
After the August 2016 Louisiana Floods

"It is so fascinating to see this map. The pattern of the distribution of red areas correlate with most realities on the ground."

Indra Sharan, OFDA, USAID
From Nepal after the M7.8 2015 Gorkha Earthquake

"During our reconnaissance missions we have used damage proxy maps (DPMs)…. My findings clearly show that the DPM published right after the event was very effective in defining collapsed buildings."

Paolo Zimmaro, UCLA/GEER
After GEER fieldwork of the 2016 Central Italy earthquakes

"After the tragic August earthquake in Amatrice, Italy, NASA's JPL produced maps of the greatest damage. These sophisticated maps will be used in the rebuilding efforts."

Barack Obama, Former President of the US
At the White House with Mateo Renzi on Oct 28, 2016

ARIA Global Response & Science

ARIA DPM/FPM on MEDIA ALOS-2, 49 items

September 2018 M7.5 Sulawesi Earthquake, Indonesia

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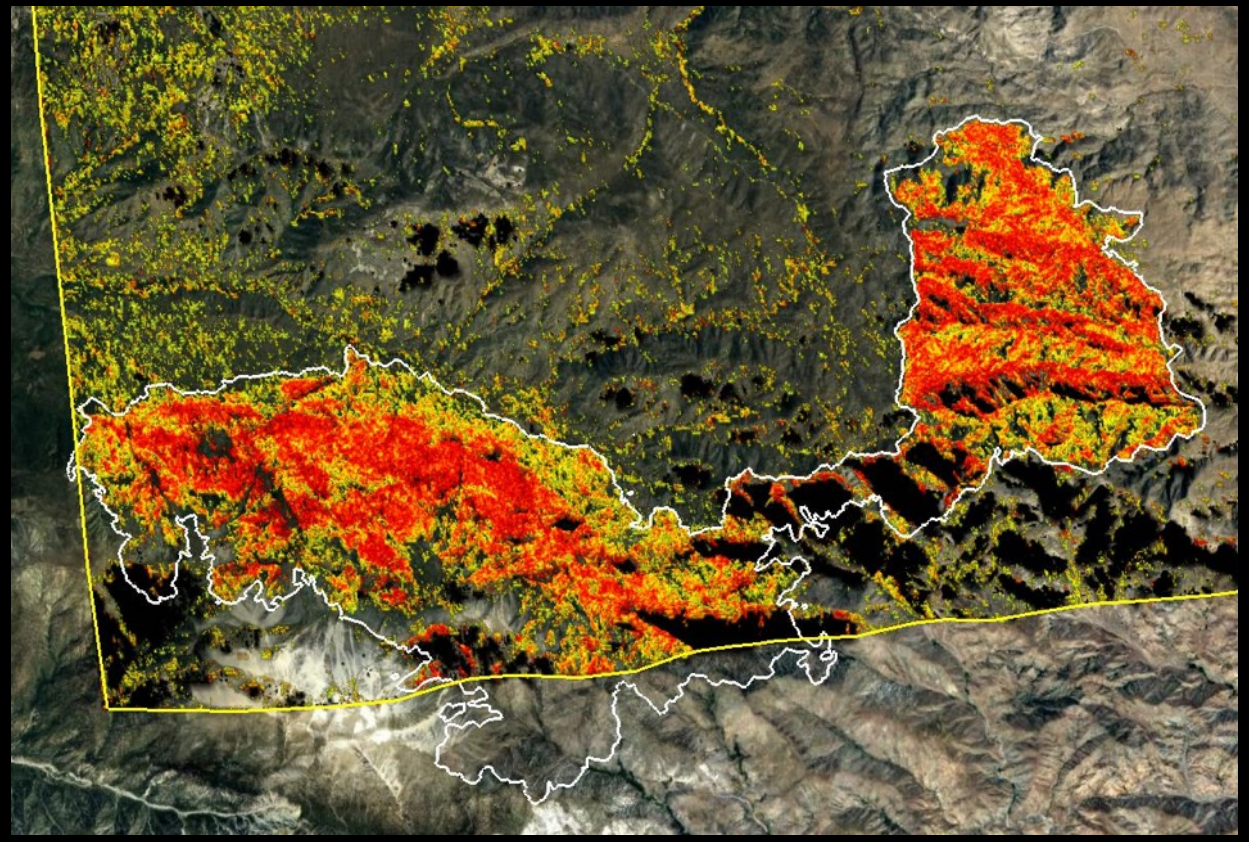
Multi-temporal Multi-polarization Interferometric Coherence Analysis July 2015 Lake Fire, California (Jung et el.)

DPM1



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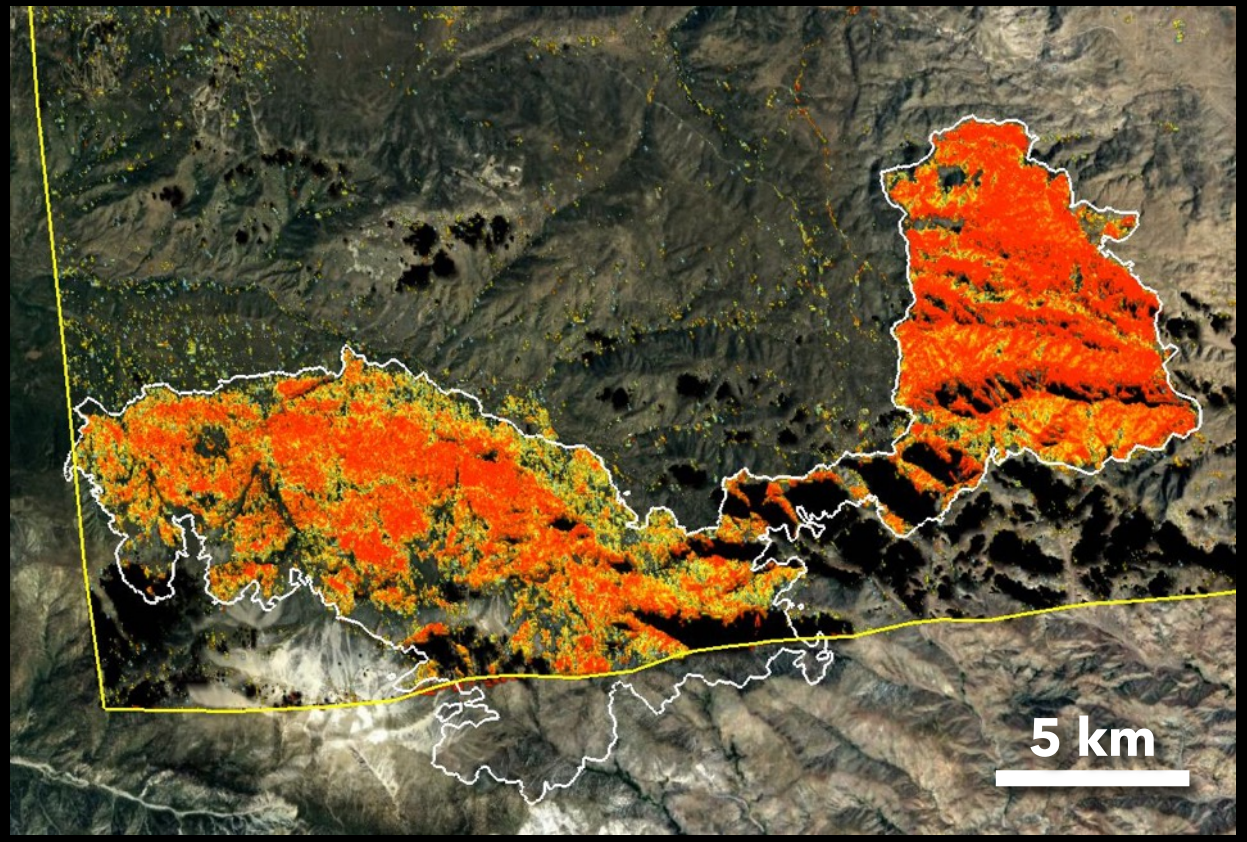
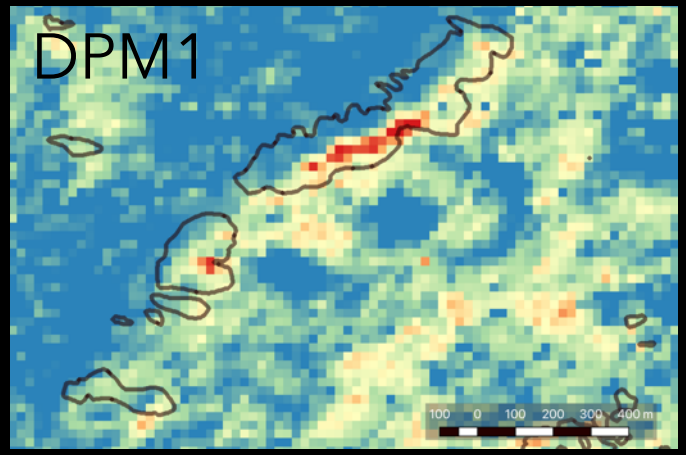
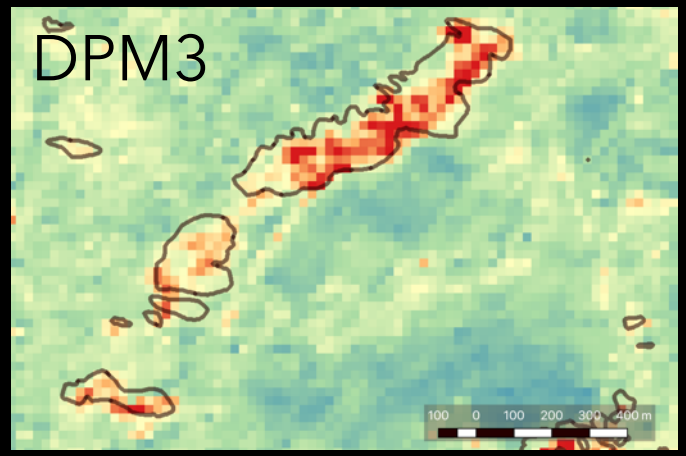


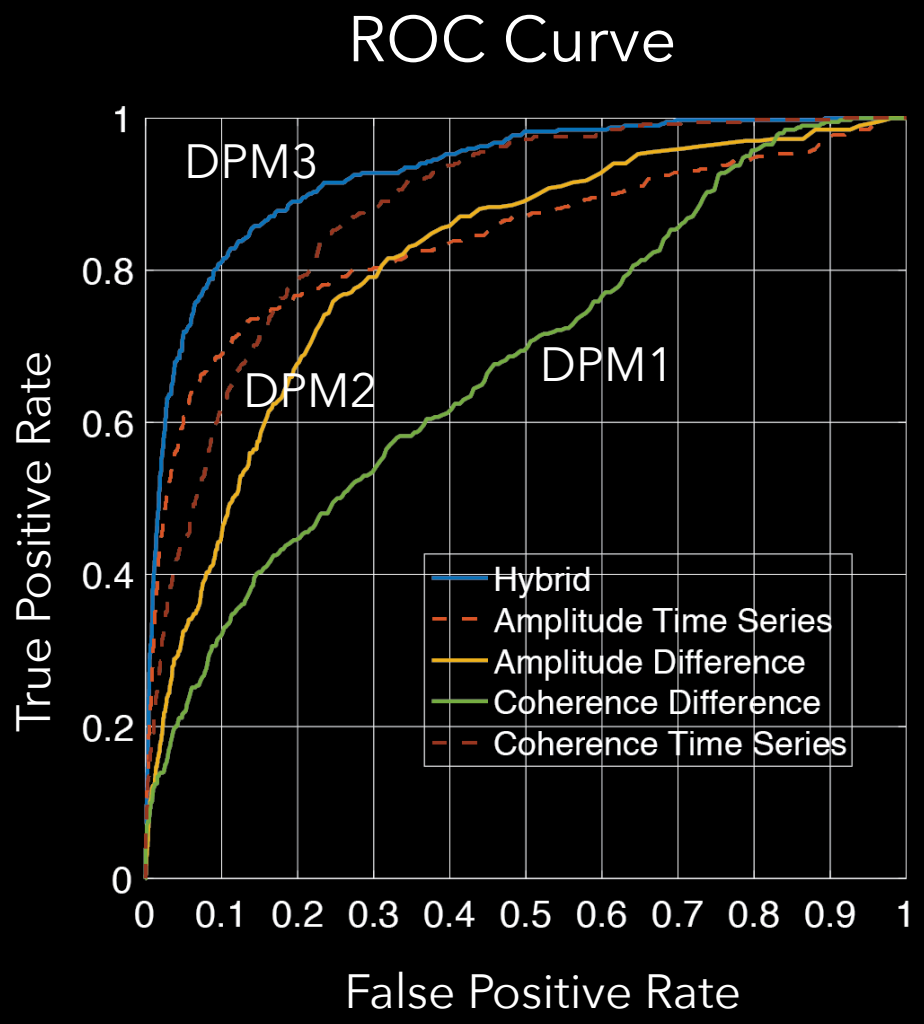
Derived from UAVSAR data

2018 Landslides Induced by the M6.6 Hokkaido Earthquake

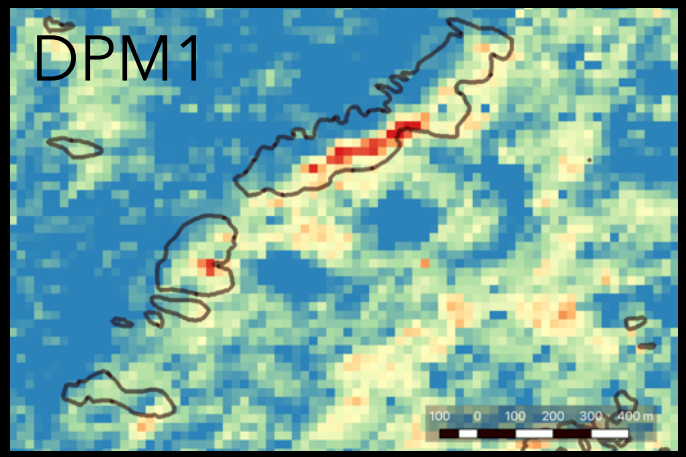


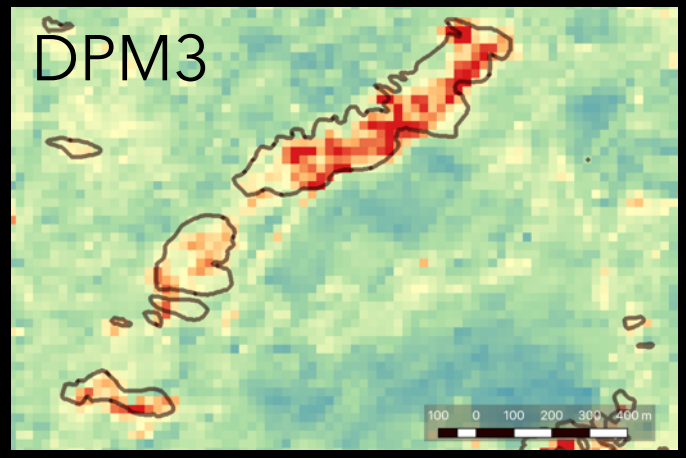


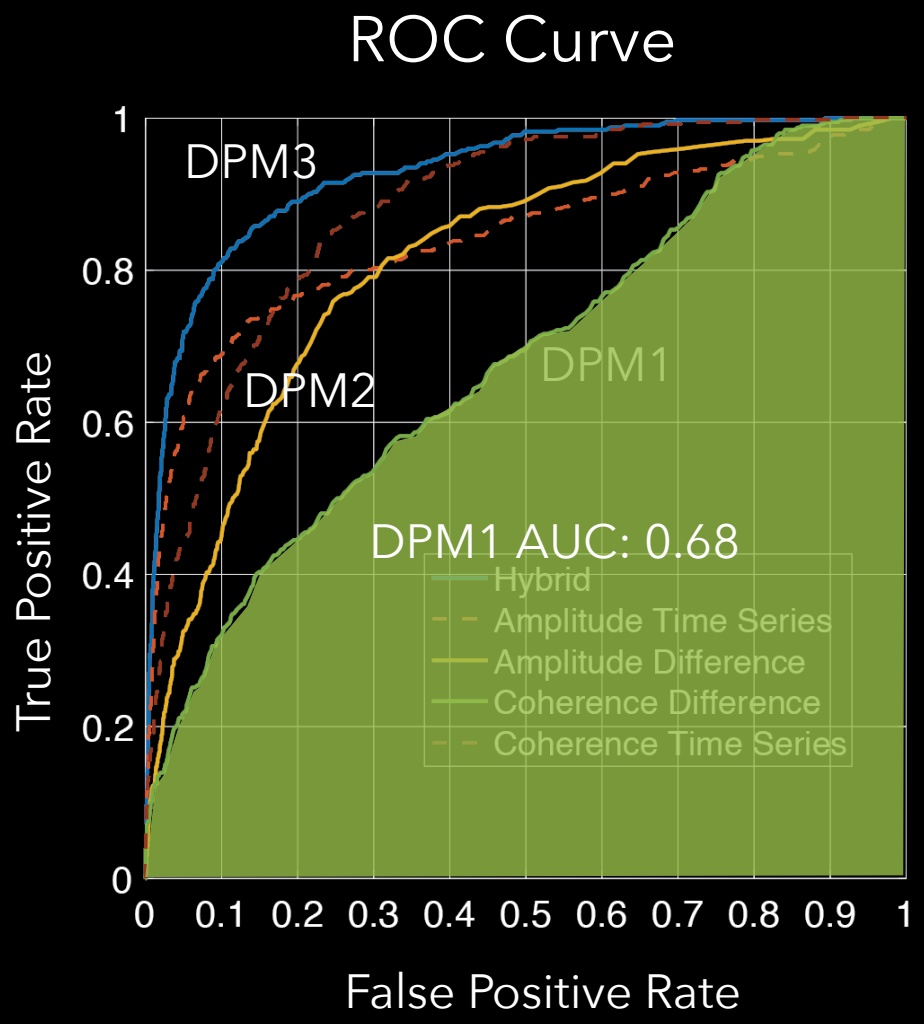
Aerial Photos by GSI



2018 Landslides Induced by the M6.6 Hokkaido Earthquake







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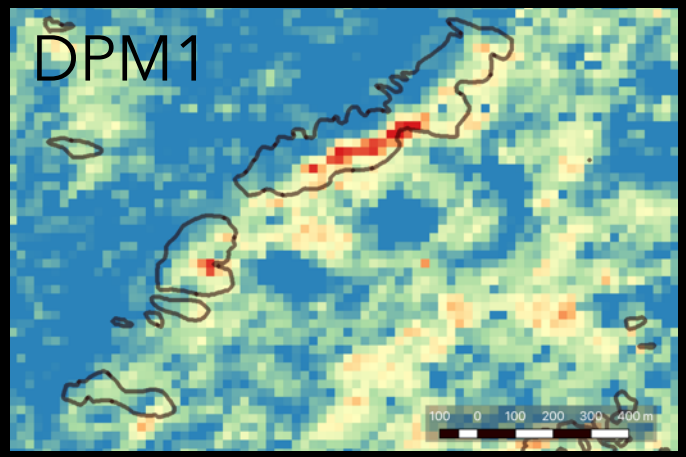
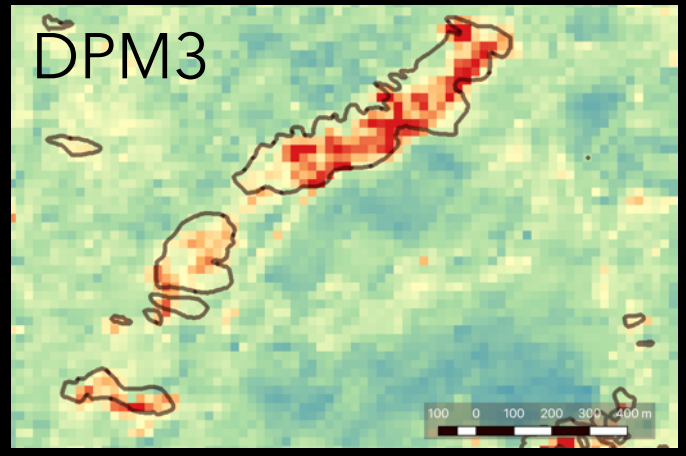
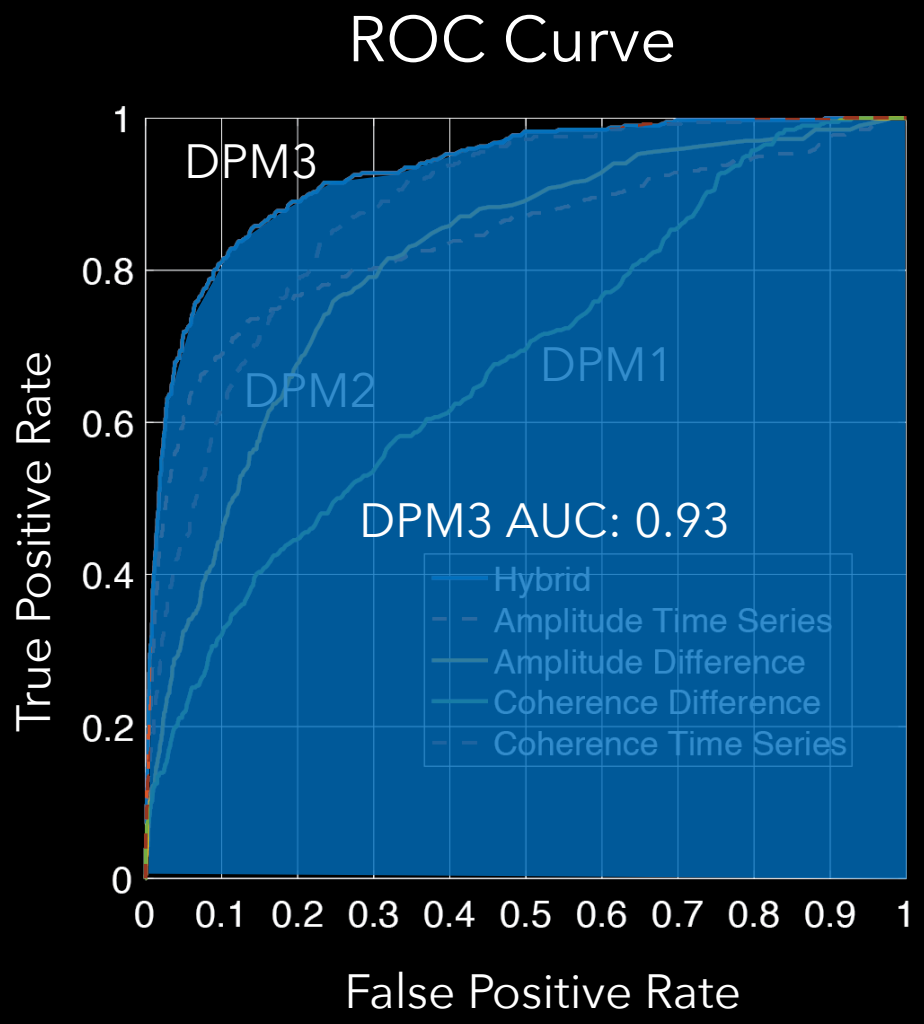


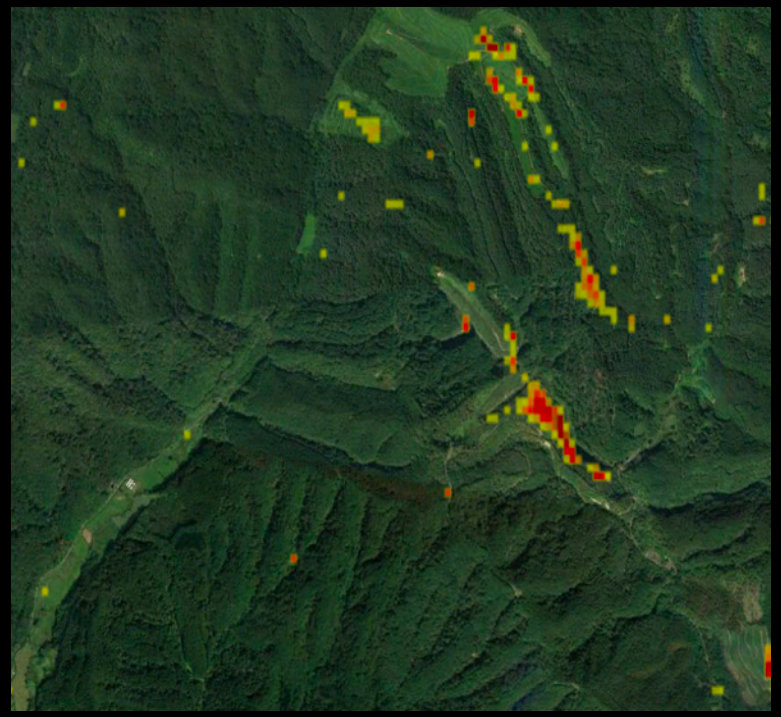




2018 Landslides Induced by the M6.6 Hokkaido Earthquake

Aerial Photos by GSI

DPM1



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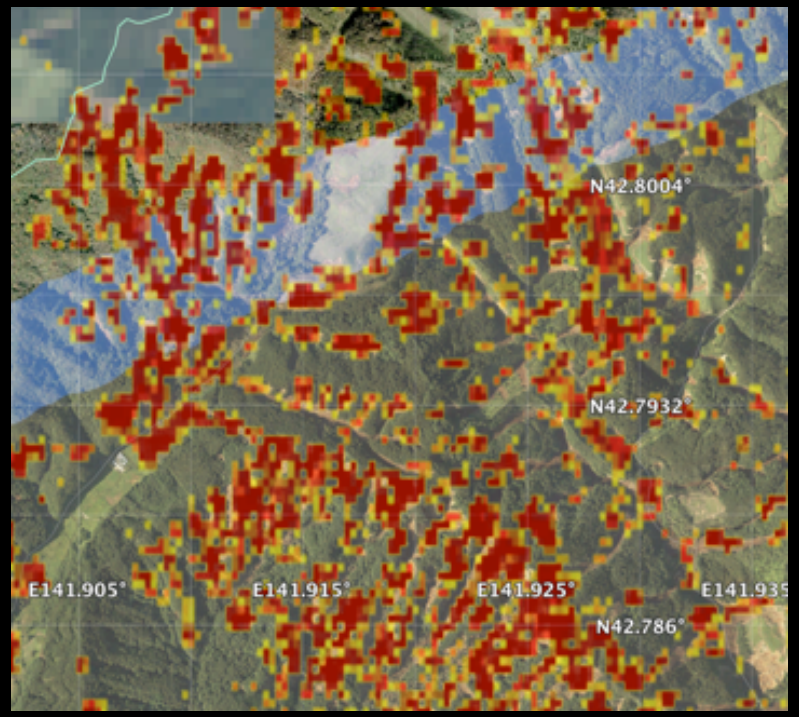
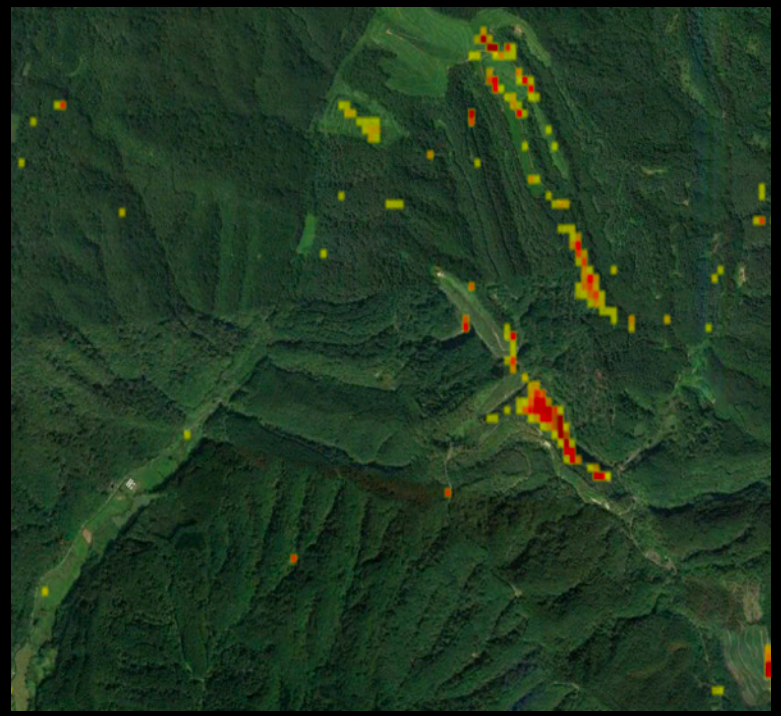


SAR Processing Latency

DPM1



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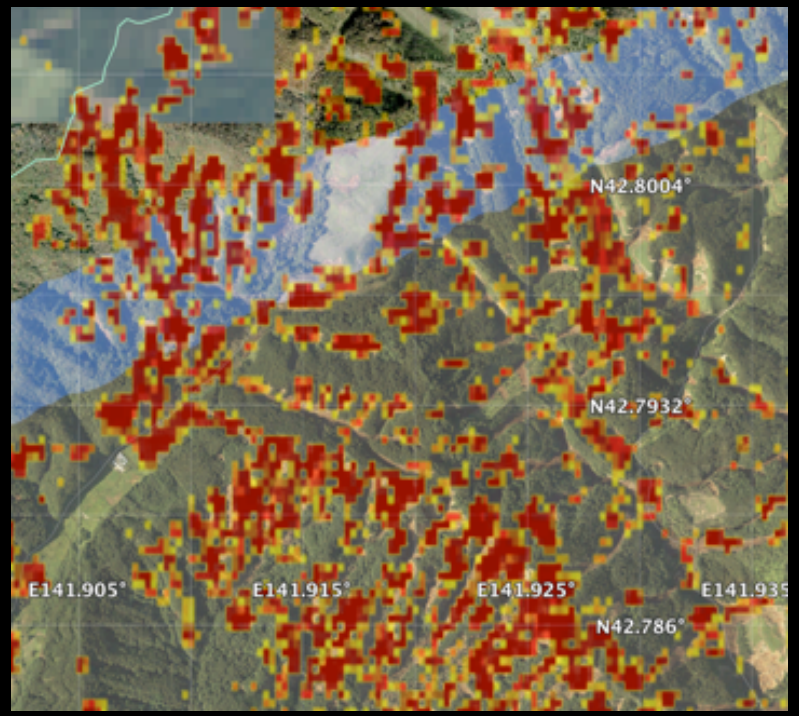
DPM2/3



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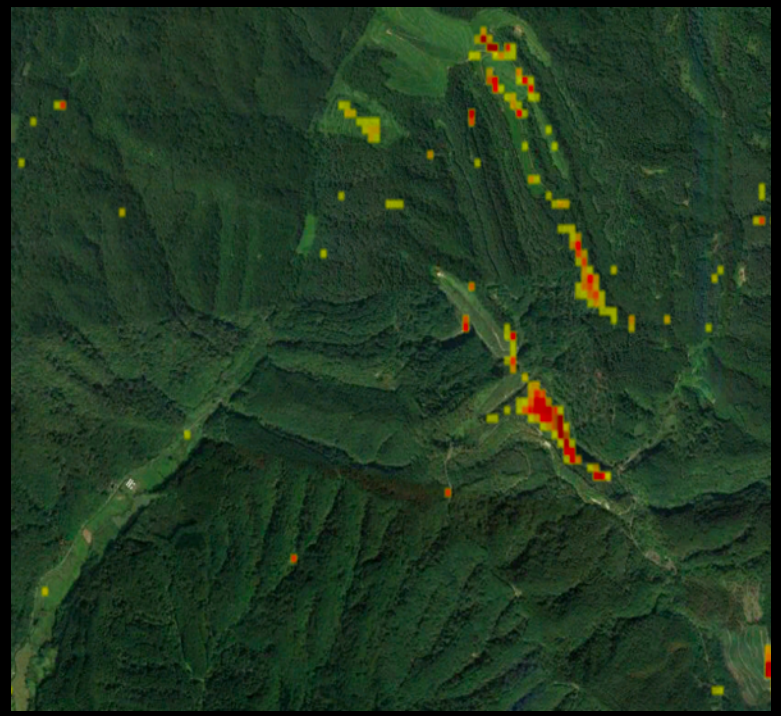
SAR Processing Latency

DPM1



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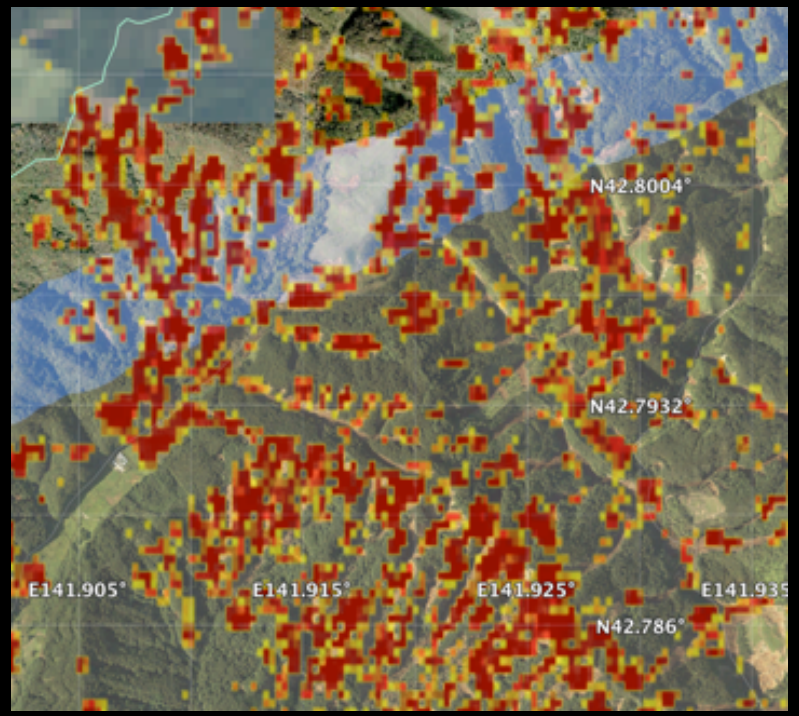
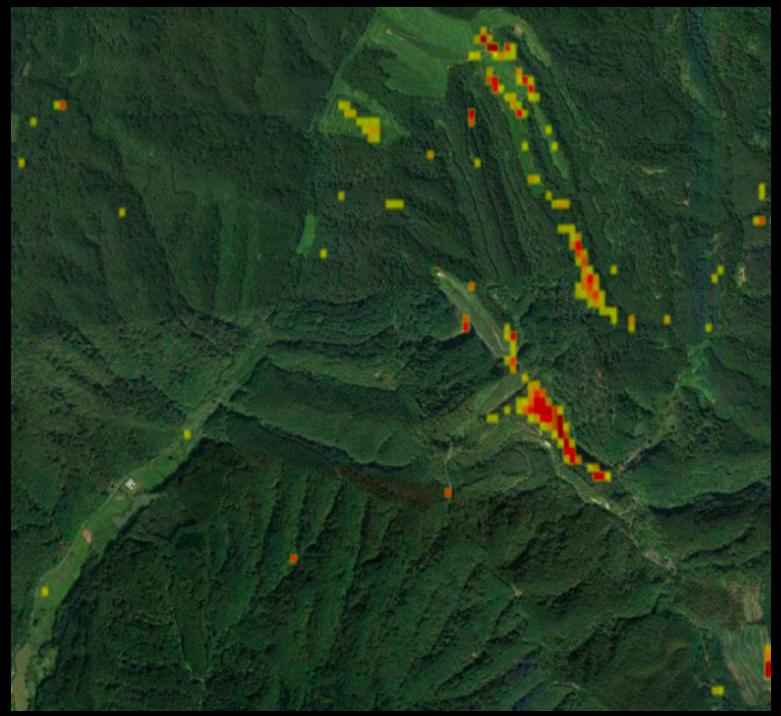
DPM2/3



Processing: 26 days → 1 hour

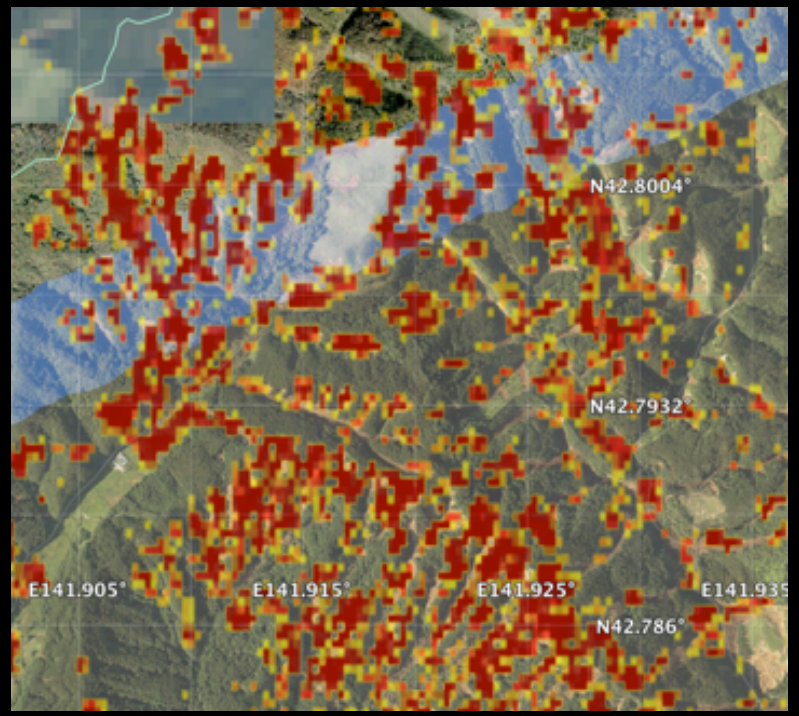
SAR Download Latency

DPM1



Processing: 1 hour
Downloading: 1.5 hours

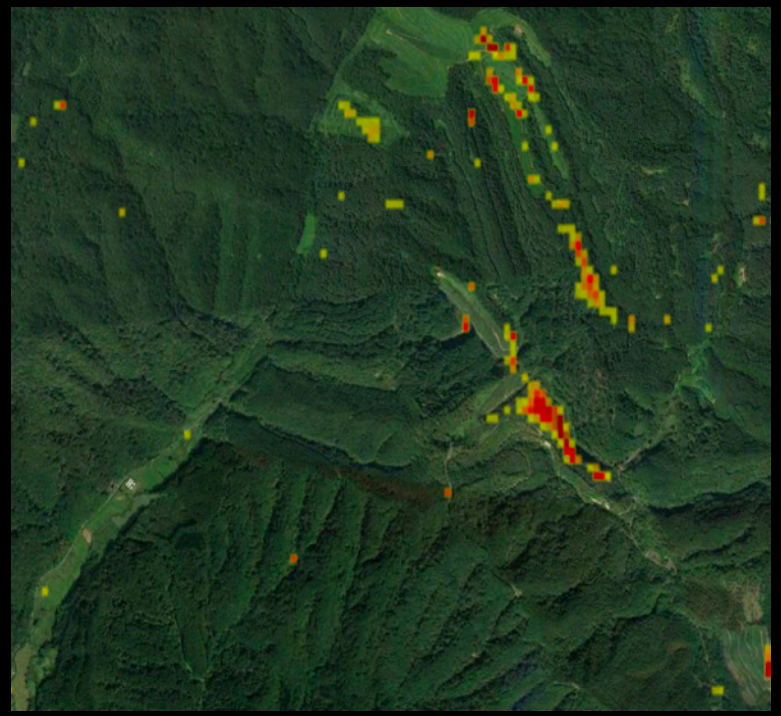
DPM2/3



Processing: 26 days → 1 hour
Downloading: 40 hours

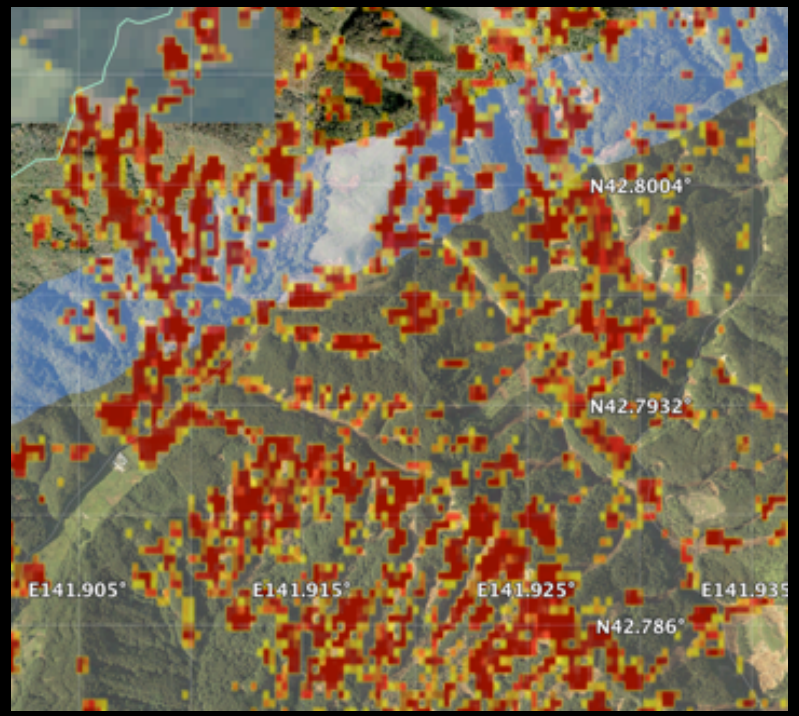
SAR Download Latency

DPM1

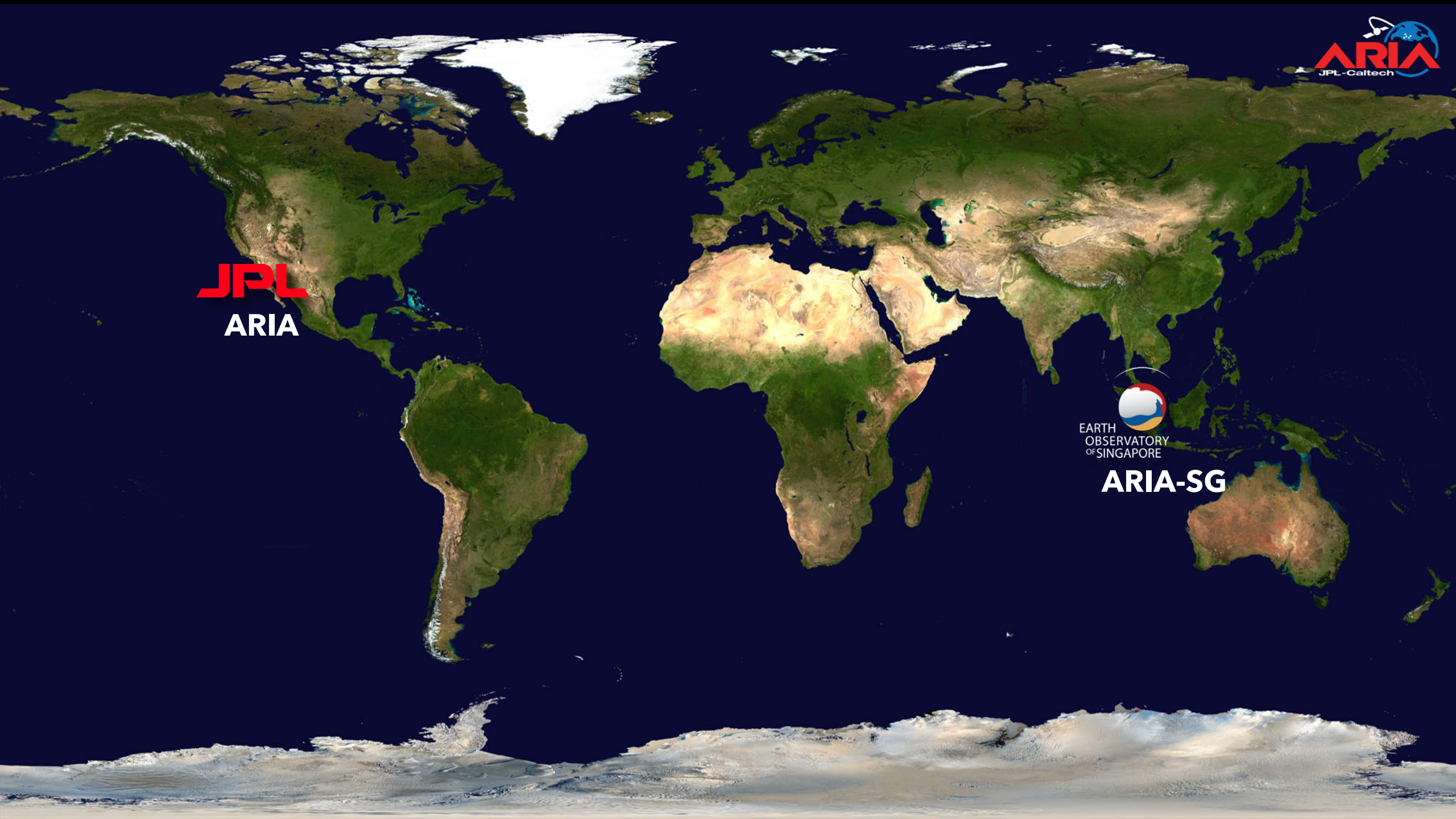


Processing: 1 hour
Downloading: 1.5 hours

DPM2/3



Processing: 26 days → 1 hour
Downloading: 40 hours → 0.5 hours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JPL-Caltech
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Discussion