Synthetic Aperture Radar for Rapid Disaster Response

Sang-Ho Yun[1]
Radar Scientist / Geophysicist, Jet Propulsion Laboratory
Disaster Response Lead of ARIA, PI of NASA Disasters projects

Jungkyo Jung[1], Cheryl Tay[2], Shi Tong Chin[2], Brian Bue[1], Oliver Stephenson[3], Yunung Nina Lin[2,4], Alok Bhardwaj[2], Kyle Bradley[2], Alexander Torres[1], Tobias Köhne[3], Eric Zhan[3], Hook Hua[1], Gerald Manipon[1], Zachary Ross[3], Eric Fielding[1], Judy Lai[1], David Bekaert[1], Susan Owen[1], Frank Webb[1], Paul Rosen[1], Mark Simons[1,3], Emma Hill[2]

1. Jet Propulsion Laboratory, California Institute of Technology
2. Earth Observatory of Singapore, Nanyang Technological University
3. California Institute of Technology
4. Academia Sinica

Jet Propulsion Laboratory
California Institute of Technology

Caltech

Source: https://paulstruestories.wordpress.com/one-rainy-night/

Basemap: Google Earth (Landsat / Copernicus)

10 km

Jakarta, Indonesia, January 2, 2020

Source: The Straits Times (Photo Courtesy: Reuters/Antara)

Kramat

North Jakarta

Kutabumi

West Jakarta

Tangerang

Jakarta

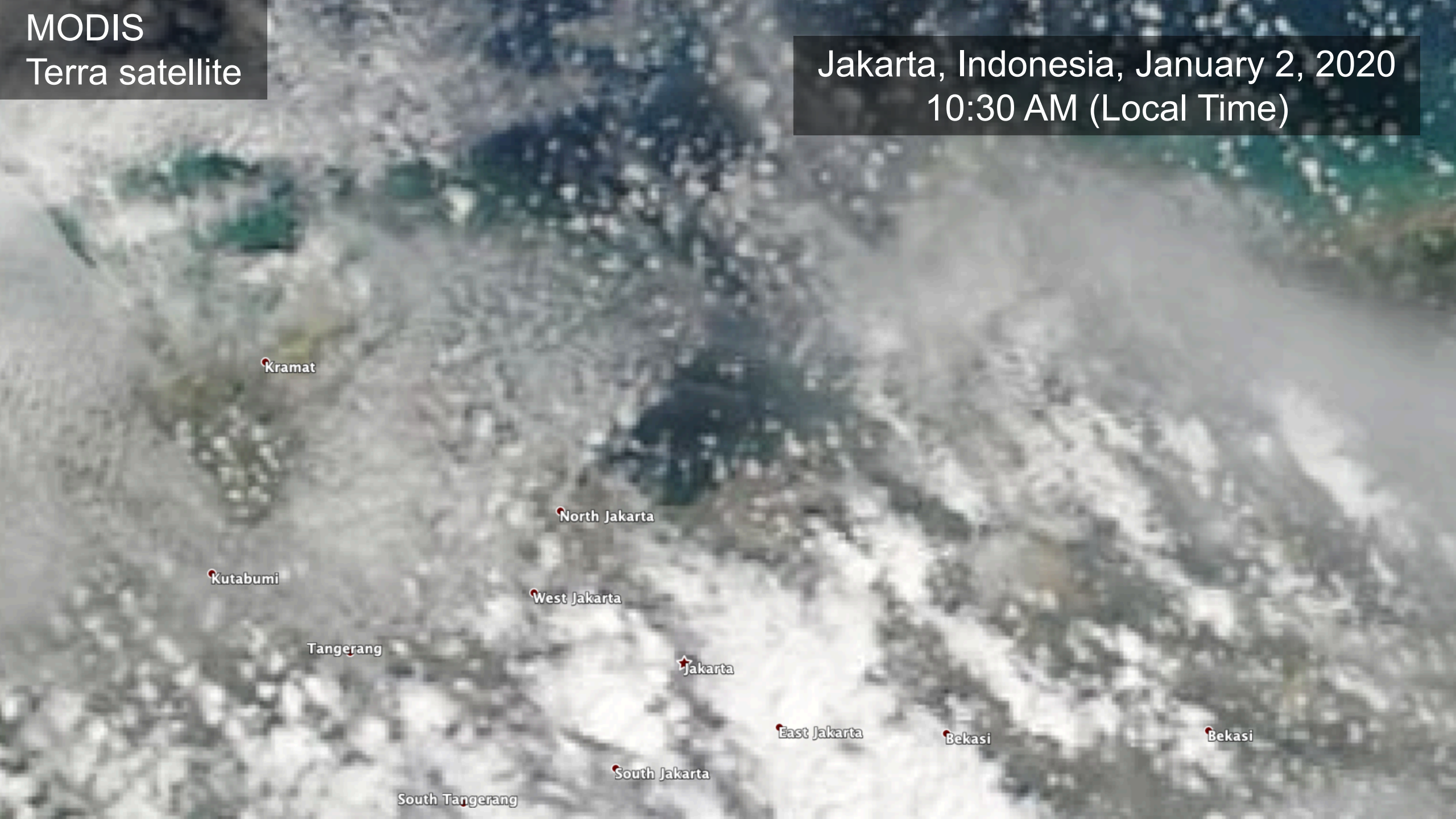
East Jakarta

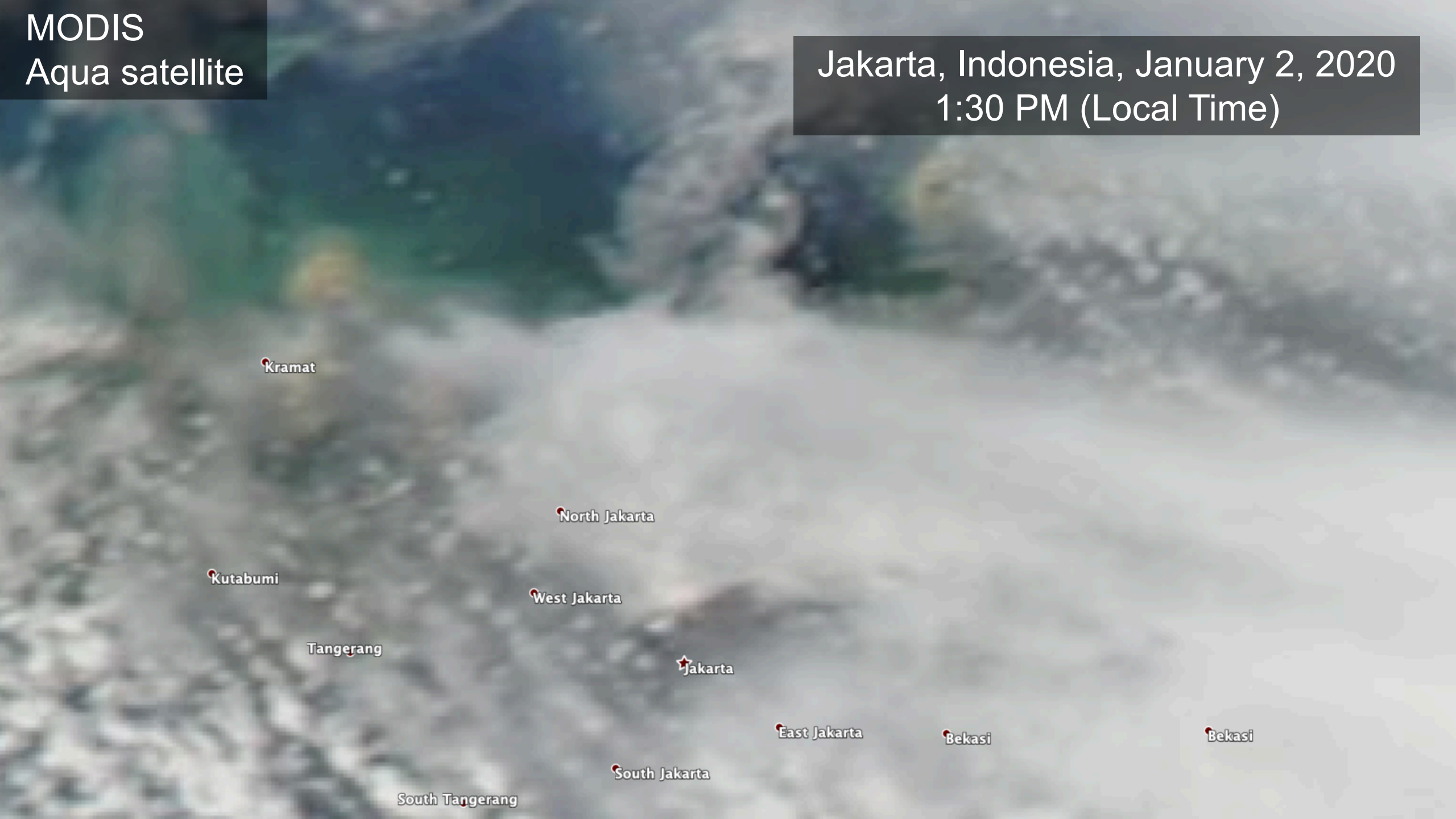
Bekasi

Bekasi

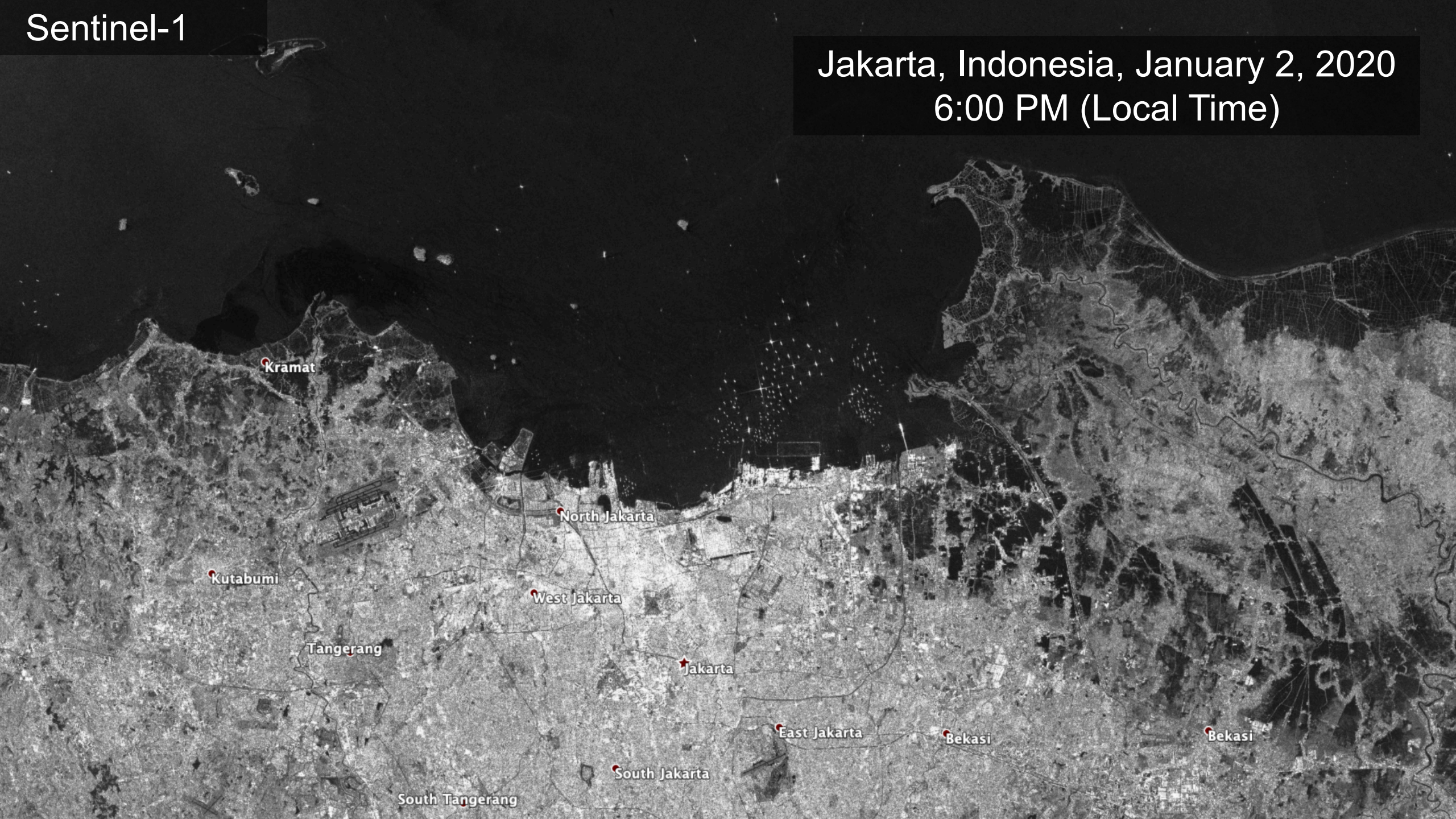
South Jakarta

South Tangerang


MODIS
Terra satellite
Jakarta, Indonesia, January 2, 2020
10:30 AM (Local Time)
Kramat
North Jakarta
Kutabumi
West Jakarta
Tangerang
Jakarta
East Jakarta
Bekasi
Bekasi
South Jakarta
South Tangerang

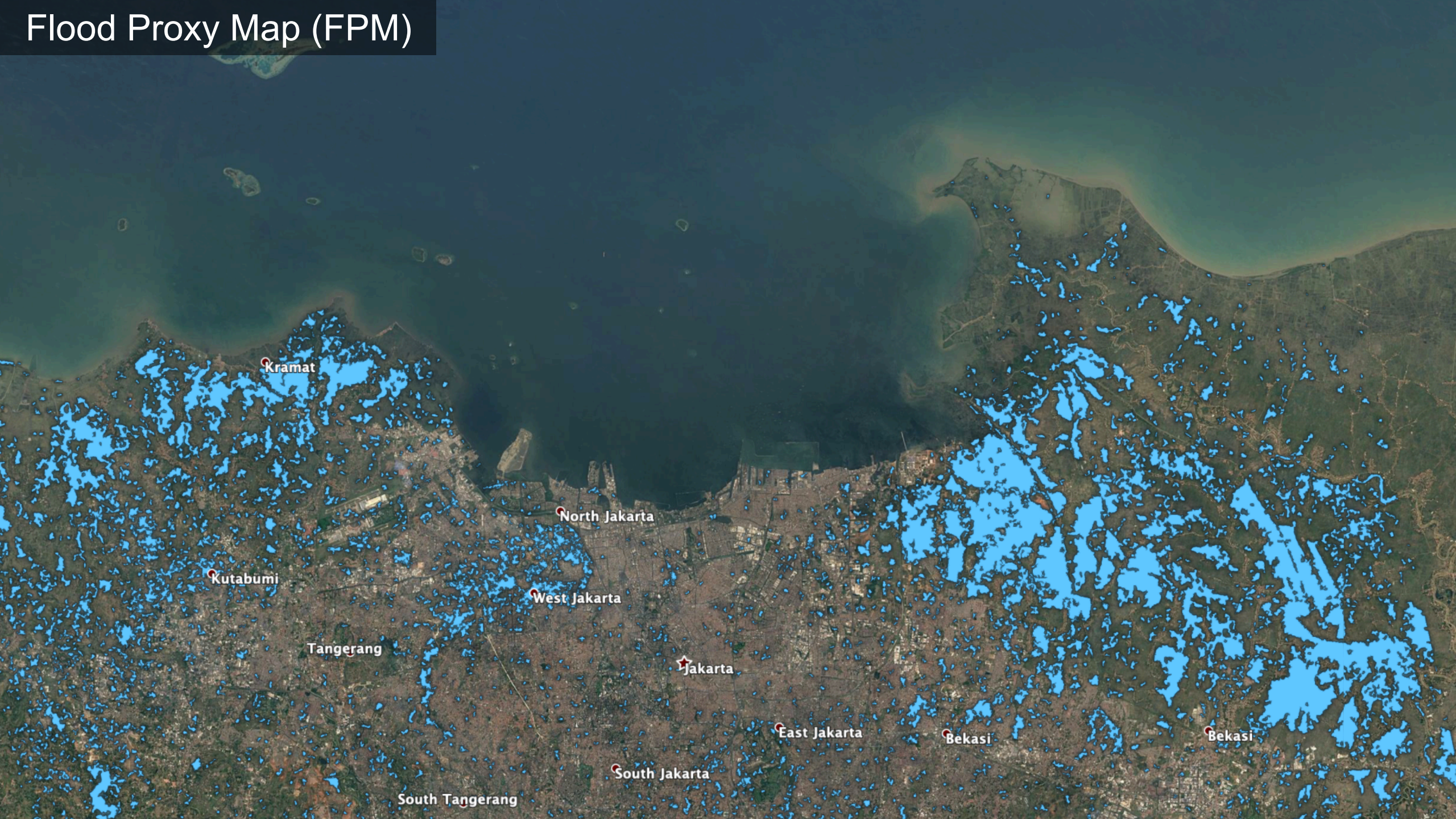

MODIS
Aqua satellite
Jakarta, Indonesia, January 2, 2020
1:30 PM (Local Time)
Kramat
North Jakarta
Kutabumi
West Jakarta
Tangerang
Jakarta
East Jakarta
Bekasi
Bekasi
South Jakarta
South Tangerang

Synthetic Aperture Radar


Sentinel-1
Jakarta, Indonesia, January 2, 2020
6:00 PM (Local Time)
Kramat
North Jakarta
Kutabumi
West Jakarta
Tangerang
Jakarta
East Jakarta
Bekasi
Bekasi
South Jakarta
South Tangerang


Sentinel-1
Jakarta, Indonesia, December 21, 2019
6:00 PM (Local Time)
Kramat
North Jakarta
Kutabumi
West Jakarta
Tangerang
Jakarta
East Jakarta
Bekasi
Bekasi
South Jakarta
South Tangerang

Flood Proxy Map (FPM)



Flood Proxy Map (FPM)

SATURDAY
04 JAN 2020
1400 HRS UTC +7

FLOODING IN JAKARTA METROPOLITAN AREA, INDONESIA
FLASH UPDATE # 3

ONE ASEAN ONE RESPONSE

KEY FIGURES

- 53* DEAD
- 1* MISSING
- 113 K* AFFECTED FAMILIES
- 409 K* AFFECTED PERSONS
- 277* INUNDATED SUB-DISTRICTS
- 173 K* DISPLACED PERSONS
- 256* AFFECTED SCHOOLS
- 1,432* DEPLOYED PERSONNEL

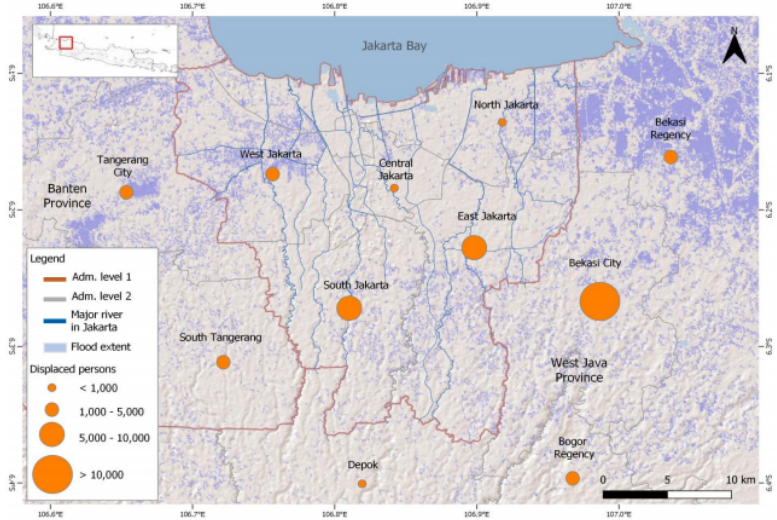
RESPONSE BY BNPB

Leading national coordination with other national agencies to support the local disaster management authority (BPBD).

Dispatching relief items, deploying personnel, disseminating information, and establishing evacuation centres.

Coordinating with the Agency for the Assessment and Application of Technology (BPPT) for weather modification operations to decrease rainfall intensities in Greater Jakarta.

*Estimations are based on data reported/confirmed by National Disaster Management Authority of Indonesia (BNPB) and other verified sources.



The current available preliminary result of floods extent analysis by Earth Observatory of Singapore (EOS ARIA-SG) - Member of Sentinel Asia. This data derived from synthetic aperture radar (SAR) by Copernicus Sentinel-1, taken on 2 January 2020. Further validation and analysis is necessary as this data is less reliable in the urban area. Nonetheless, based on this preliminary result, it is showed that the most massive floods extent is in Bekasi with the highest number of displaced people compare to other area. In contrary, Depok area shows the least inundation extent and the least affected persons as per this reporting period.

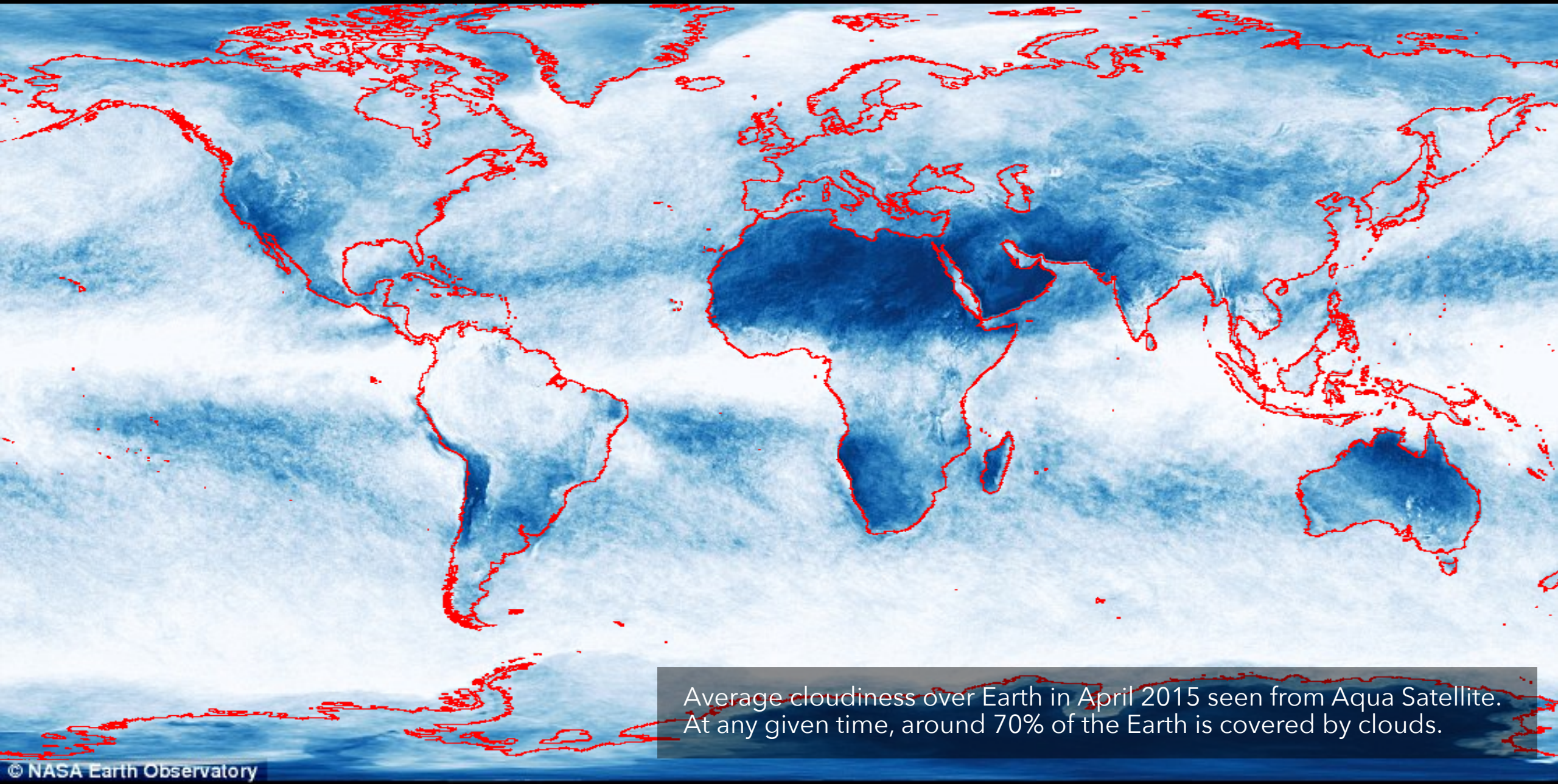
DATA SOURCES
AHA Centre Disaster Monitoring & Response System (DMRS); ASEAN Disaster Information Network; Pacific Disaster Center (PDC Global); Indonesia: National Disaster Management Authority (BNPB); Meteorology, Climatology, and Geophysical Agency (BMKG); Agency for the Assessment and Application of Technology (BPPT); Various news sources

Our mailing address is:
AHA Centre,
GRAHA BNPB 13th Floor,
Jl. Raya Pramuka Kav. 38,
Jakarta 13120 Indonesia

Kramat
Kutabumi
Tangerang
South Tangerang
South Jakarta
Bekasi

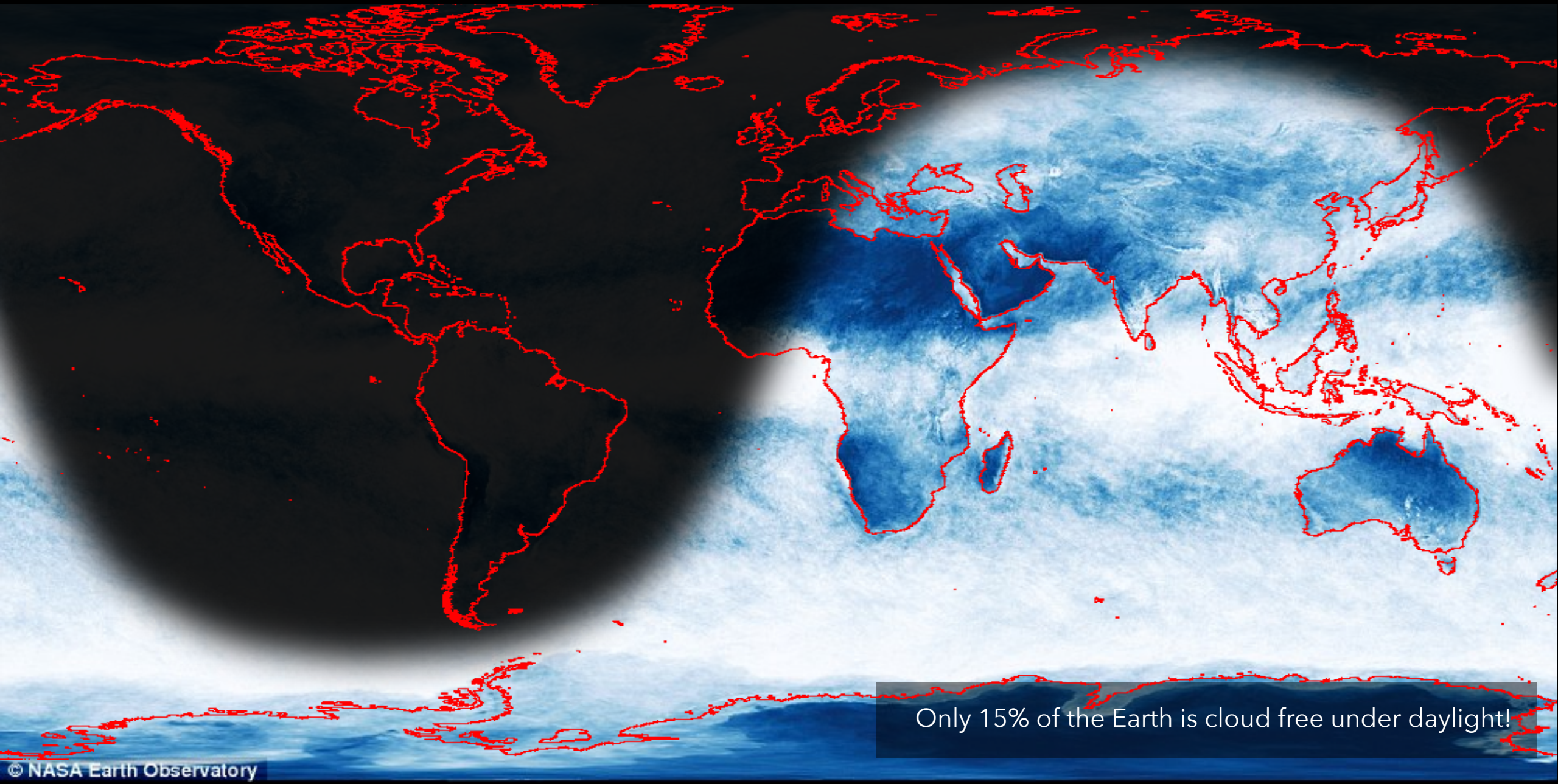

MODIS
Terra satellite
Jakarta, Indonesia, December 21, 2019
10:30 AM (Local Time)
Kramat
North Jakarta
Kutabumi
West Jakarta
Tangerang
Jakarta
East Jakarta
Bekasi
Bekasi
South Jakarta
South Tangerang

Optical Sensors Need Cloud-free Sky

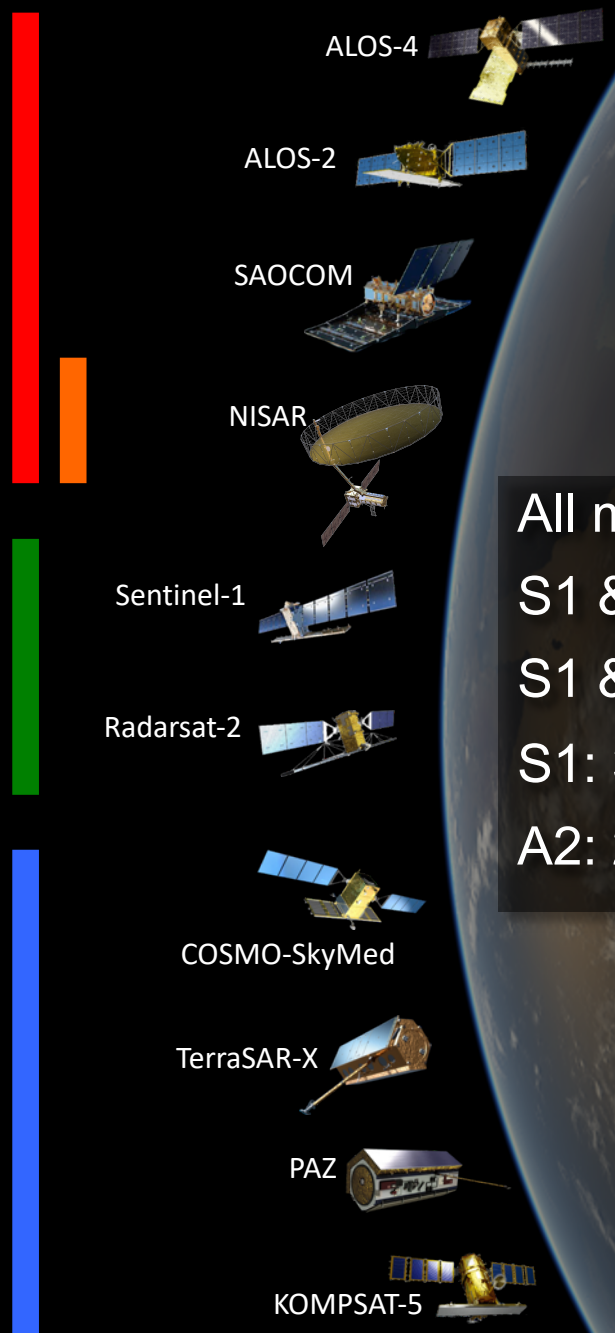


Average cloudiness over Earth in April 2015 seen from Aqua Satellite.
At any given time, around 70% of the Earth is covered by clouds.

SAR Sensors See Through Clouds Day and Night



Overpass Latency of SAR Missions



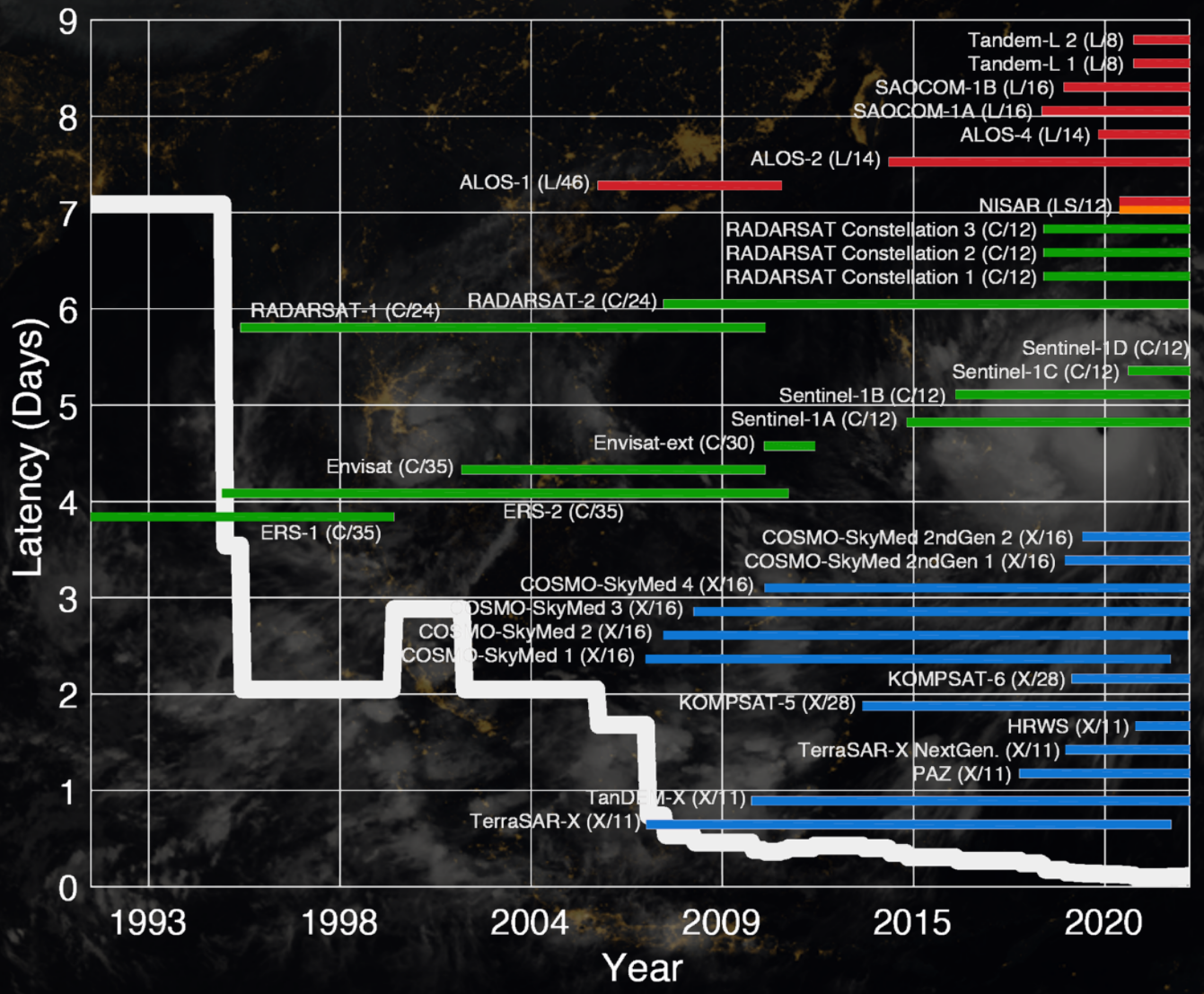
All missions: 6 h

S1 & A2 & CSK: 10 h

S1 & A2: 20 h

S1: 30 h

A2: 2.8 days



ARIA
JPL-Caltech

JPL

Integrating
Space Geodesy
Seismology
Modeling

Seismological Laboratory
California Institute of Technology

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

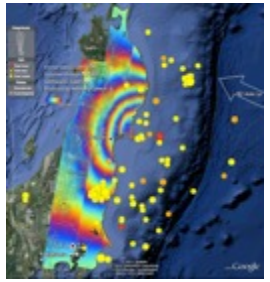
Radar Sensors

GPS Networks

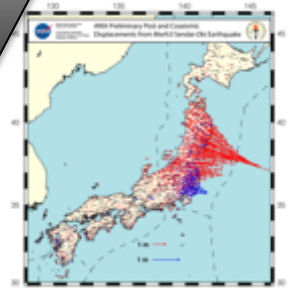
Seismic Networks

Optical Sensors

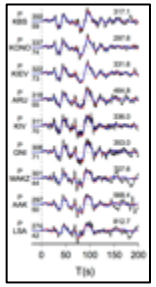
Automated Data Collection & Processing



Radar



GPS



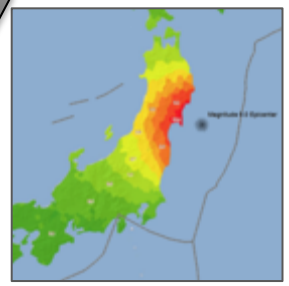
Seismology

amazon web services

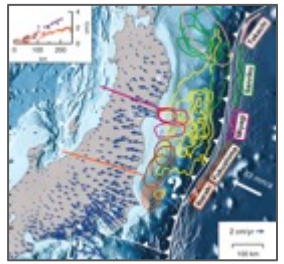
Monitoring & Near Real-Time Assessment

Potential Partners

Building Damage
& Inundation



Permanent
Ground Deformation



High-Resolution
Hazard Assessment
from Fault Models

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

Anne Rosinski
Calif. Geol. Survey

"We have high hopes for ARIA."

Keiko Saito
World Bank

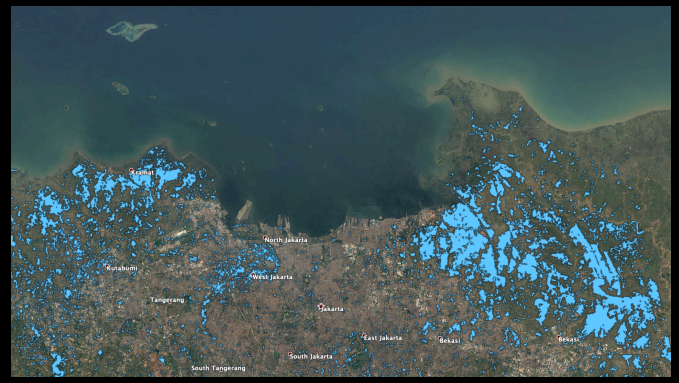
esa
JAXA
agenzia spaziale italiana
ASF
EARTH OBSERVATORY OF SINGAPORE
DigitalGlobe
planet.
The World Bank

USGS science for a changing world
OES
CAL FIRE
USAID FROM THE AMERICAN PEOPLE
GEER
EERI

Back to Flood Mapping

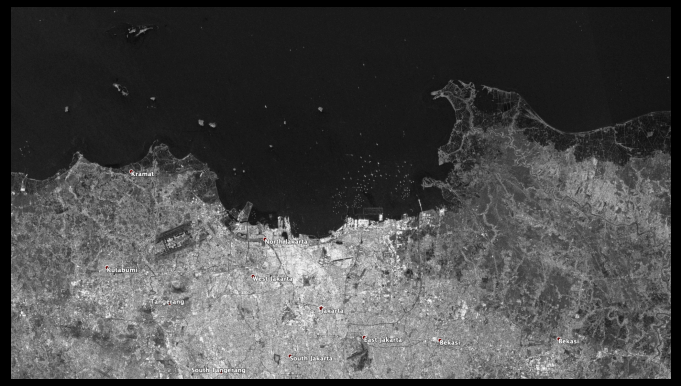
Flood Mapping (FPM1)

SAR image: $c = Ae^{i\varphi}$

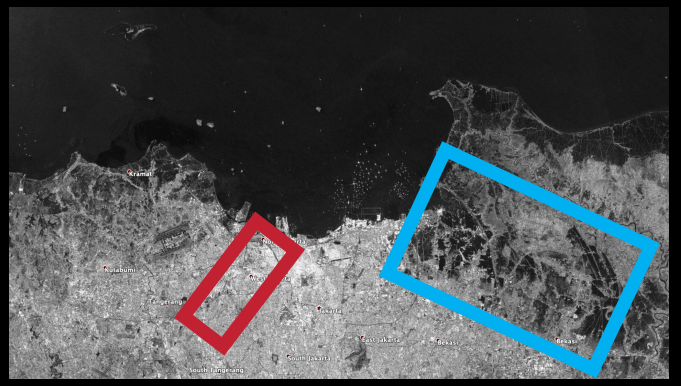


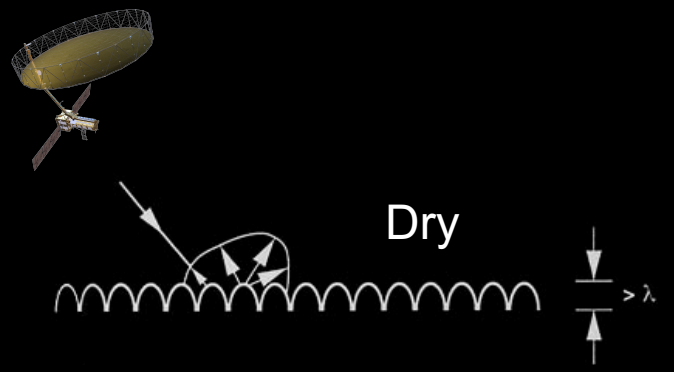
$log_{10}(\frac{A_c}{A_p})$

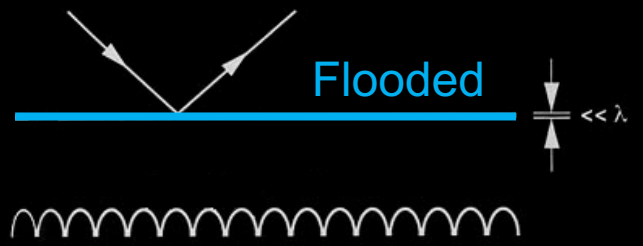
Pre-event SAR Amplitude (Ap)

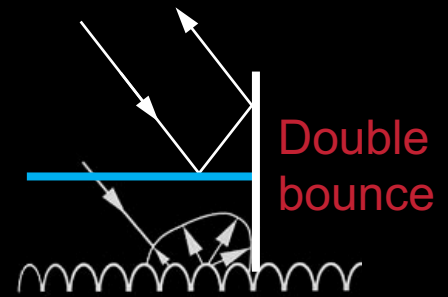


Co-event SAR Amplitude (Ac)



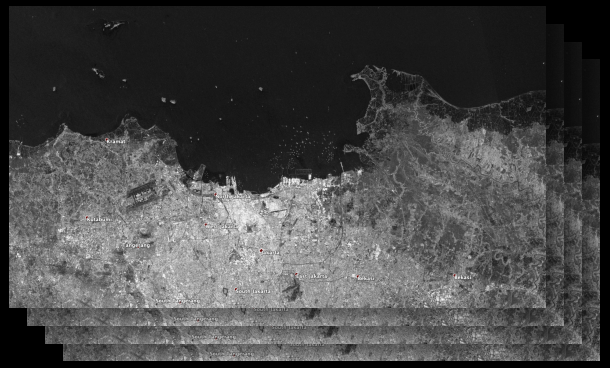




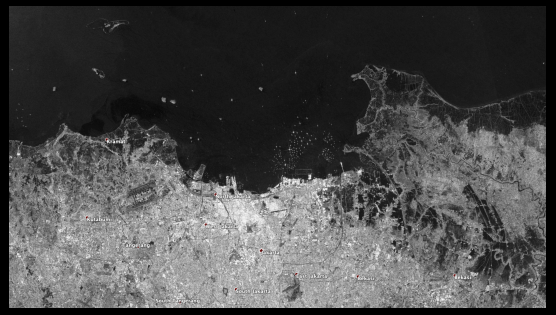


FPM2: Multi-temporal SAR with Bayesian Framework

(Lin et al., Remote Sensing, 2019)



72 pre-event scenes



1 co-event scene

FPM2, for the first time in response mode

SAR image: $c = Ae^{i\varphi}$

Backscattering coefficient: $\sigma^0 = 10log_{10}(A^2)$

Normalize (z-score): $z = \frac{\sigma^0 - m_{pre}}{s_{pre}}$

Bayes' Theorem:

$$P(F|z) = \frac{P(z|F)\,P(F)}{P(z|F)\,P(F) + P(z|{\sim}F)\,P(\sim F)}$$

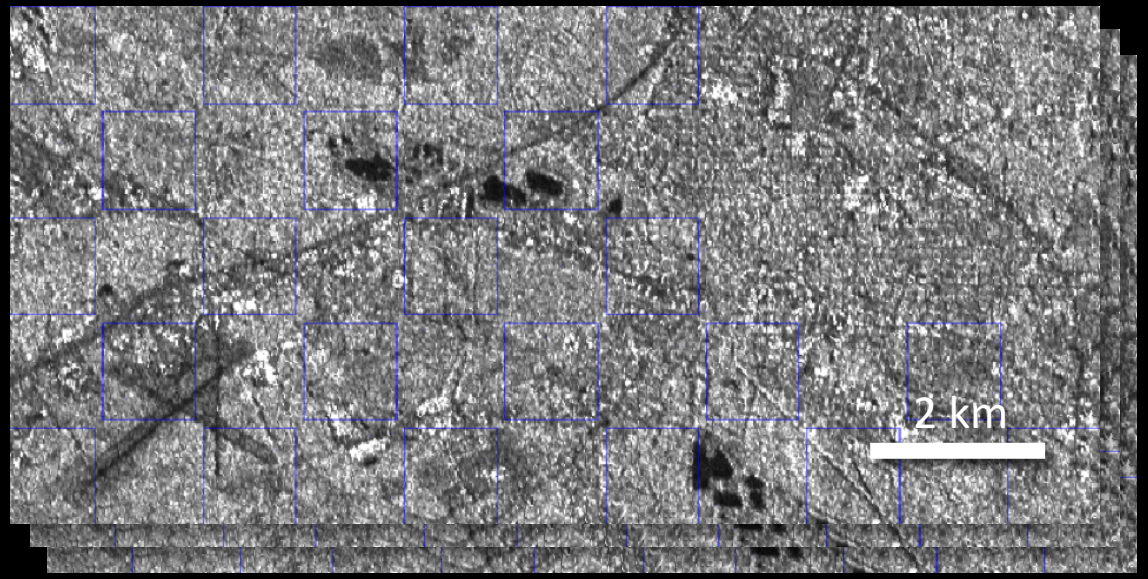
Cheryl Tay (NTU)

Shi Tong Chin (NTU)

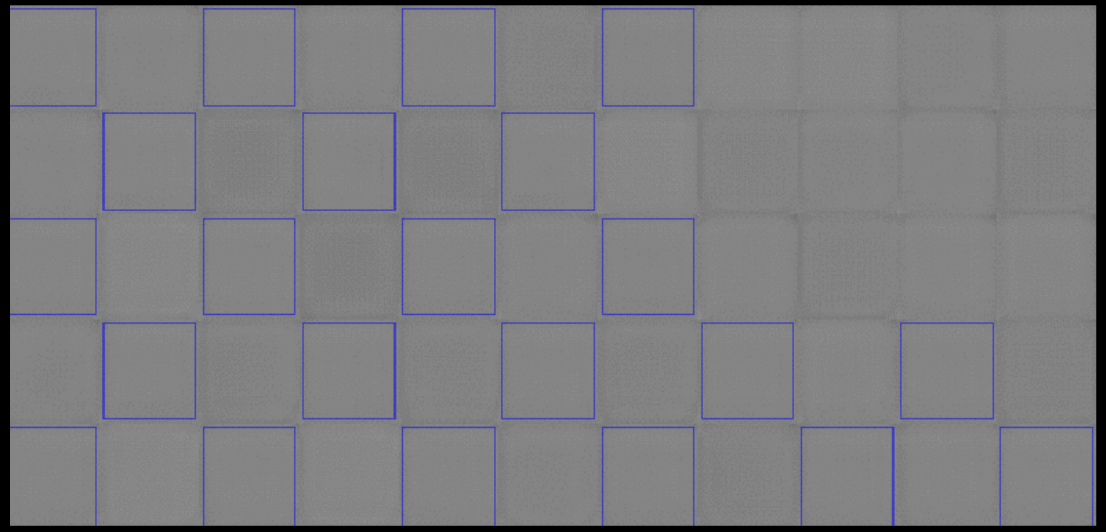
Nina Lin (AS)

FPM3: Deep Learning (PredRNN++)

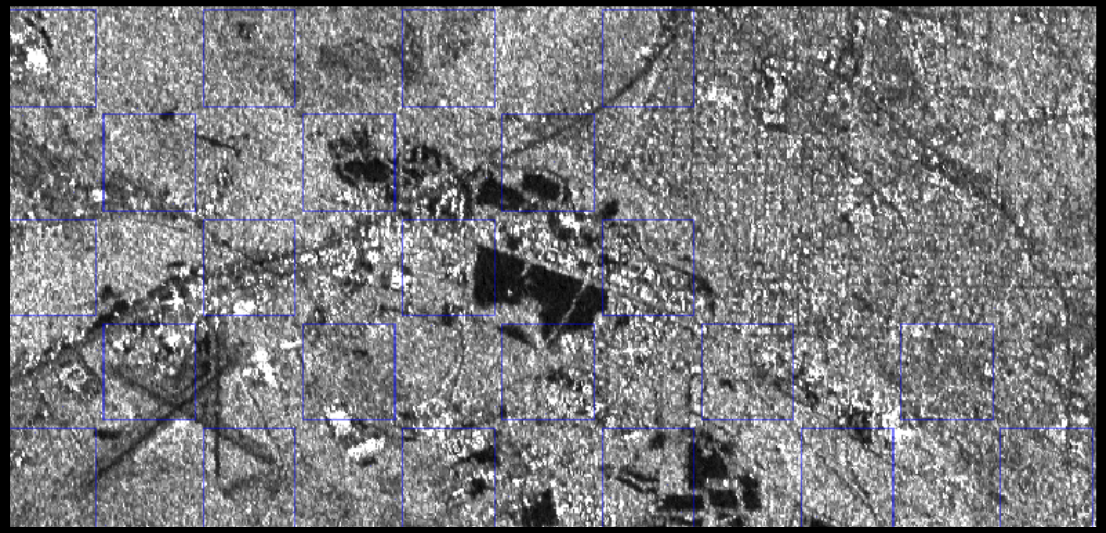
Dry Observations (pre-flood n=5 SAR images)



Predicted Model at n+1



Flood Observation at n+2 (co-event SAR image)



Brian Bue
(JPL)

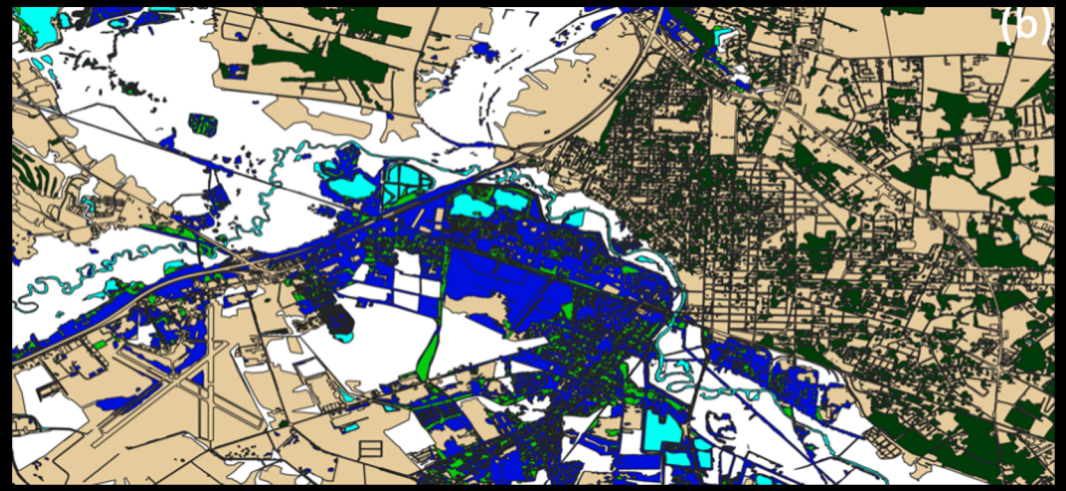
- CNN + RNN for spatiotemporal sequence prediction
- Blue squares: test tiles
- Elsewhere: training tiles
- Training time: ~30 minutes

Anomaly Score Maps

Brian Bue
(JPL)

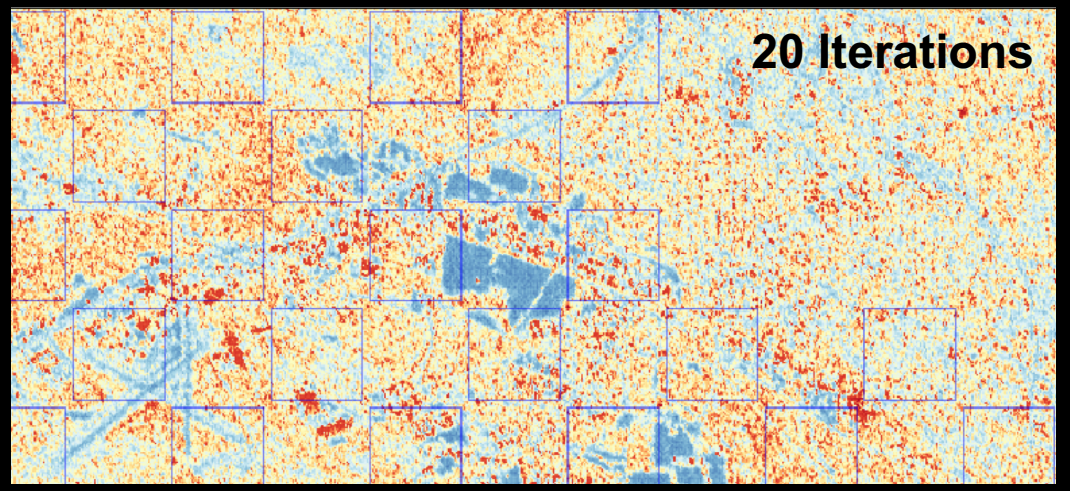
Alok Bhardwaj
(NTU)

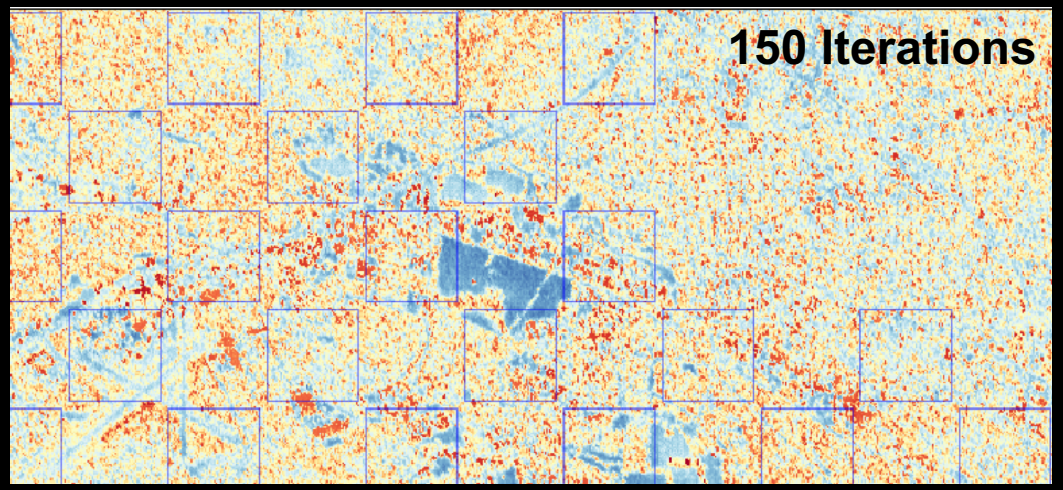
Validation Map
(NOAA aerial photos)

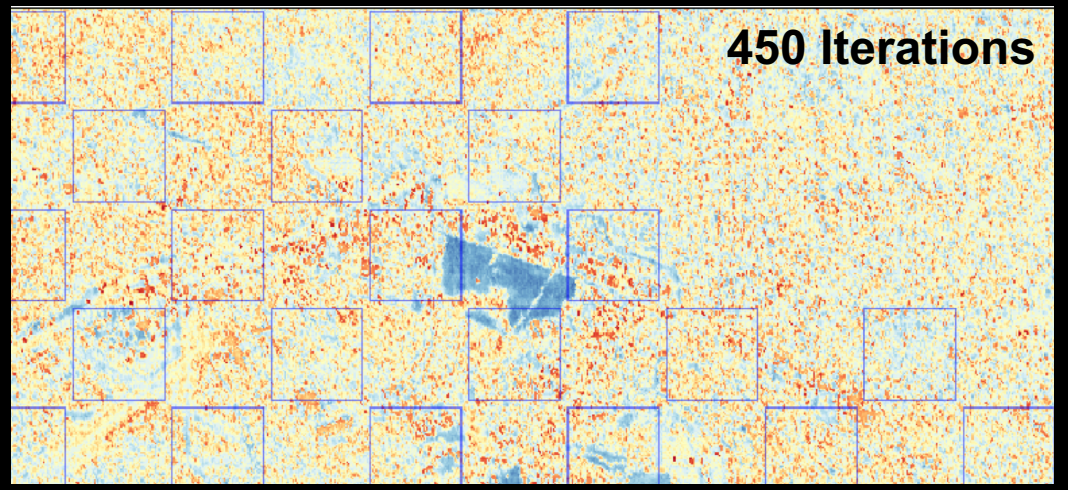


Negative Anomaly

Positive Anomaly







Anomaly Score Maps

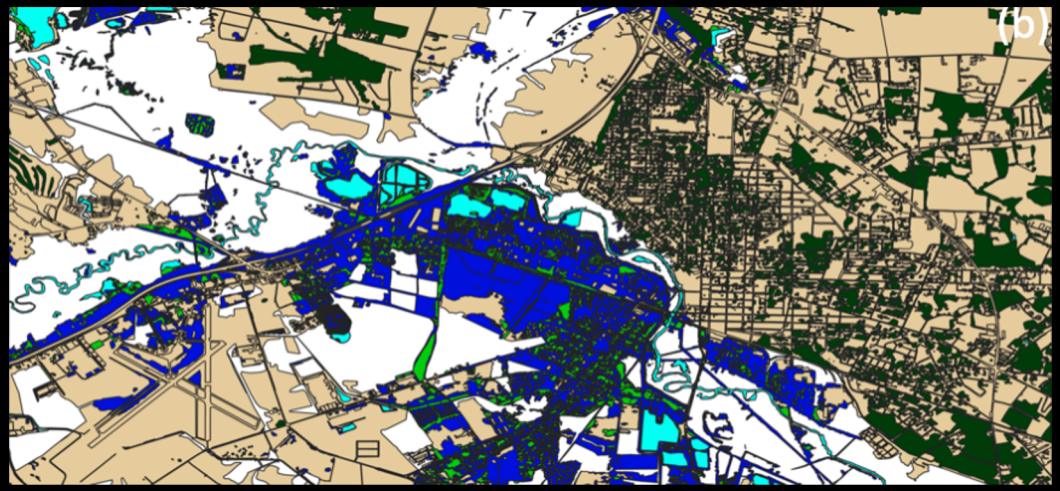
Brian Bue
(JPL)

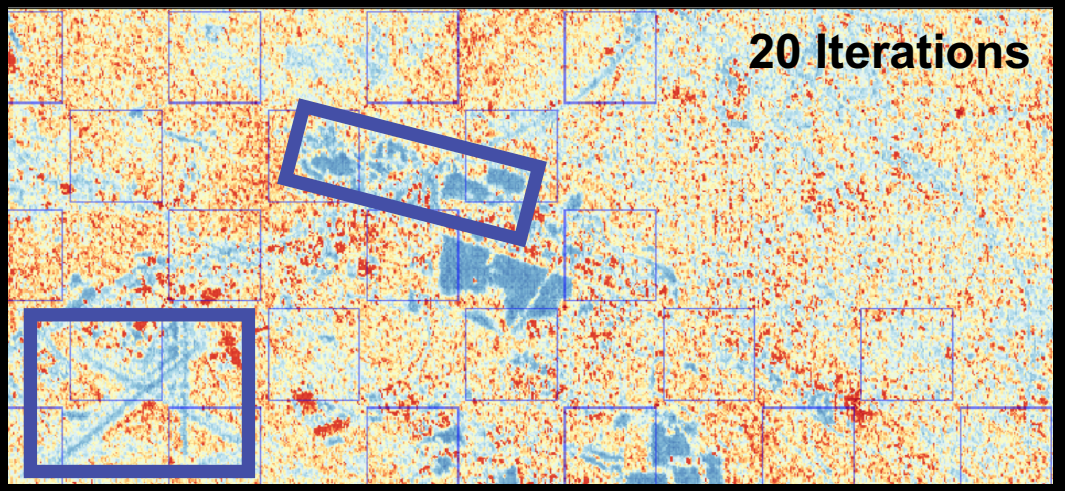
Alok Bhardwaj
(NTU)

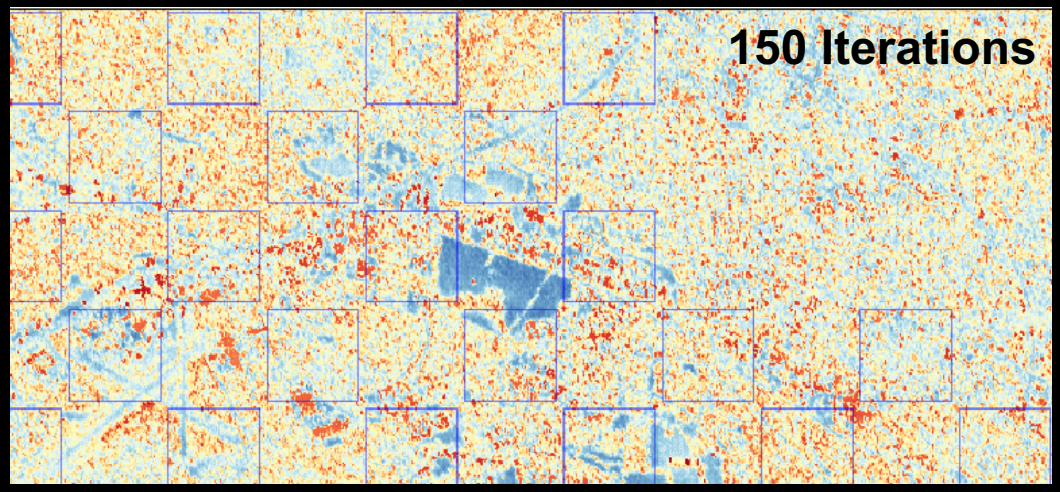
Validation Map
(NOAA aerial photos)

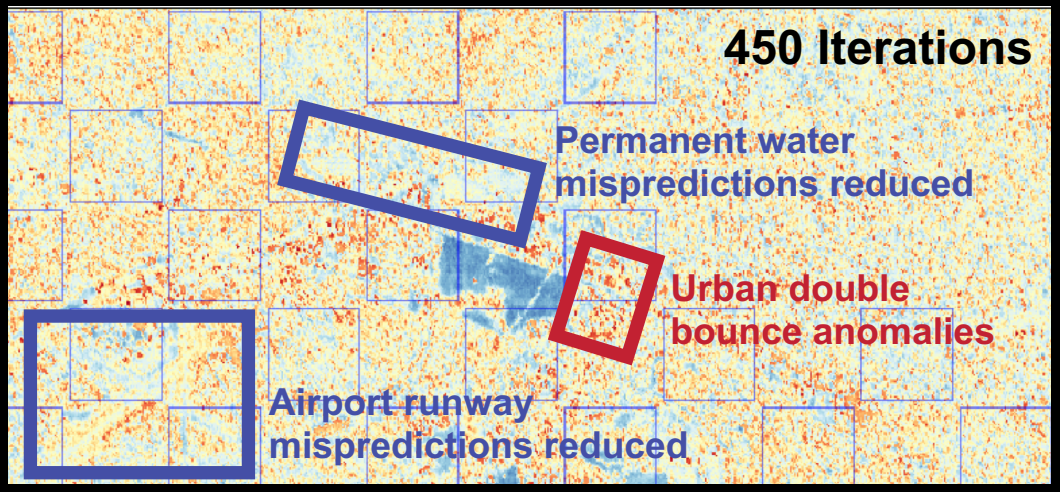
Negative Anomaly

Positive Anomaly









Damage Mapping

Damage Proxy Map

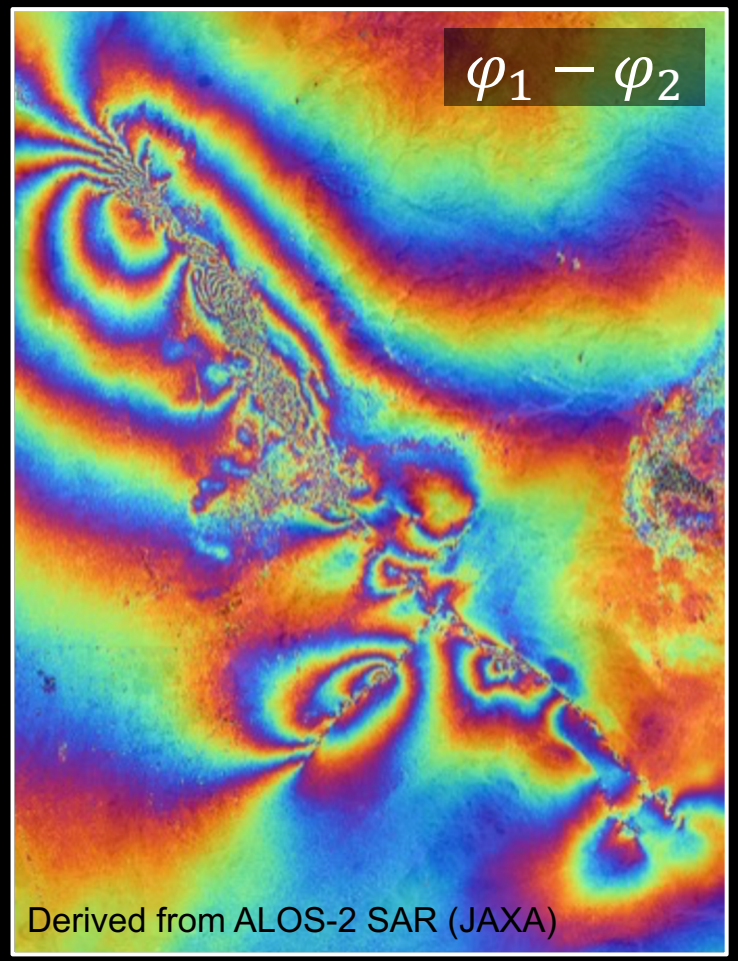
Ridgecrest Earthquakes, California 2019

SAR image: $c = Ae^{i\varphi}$

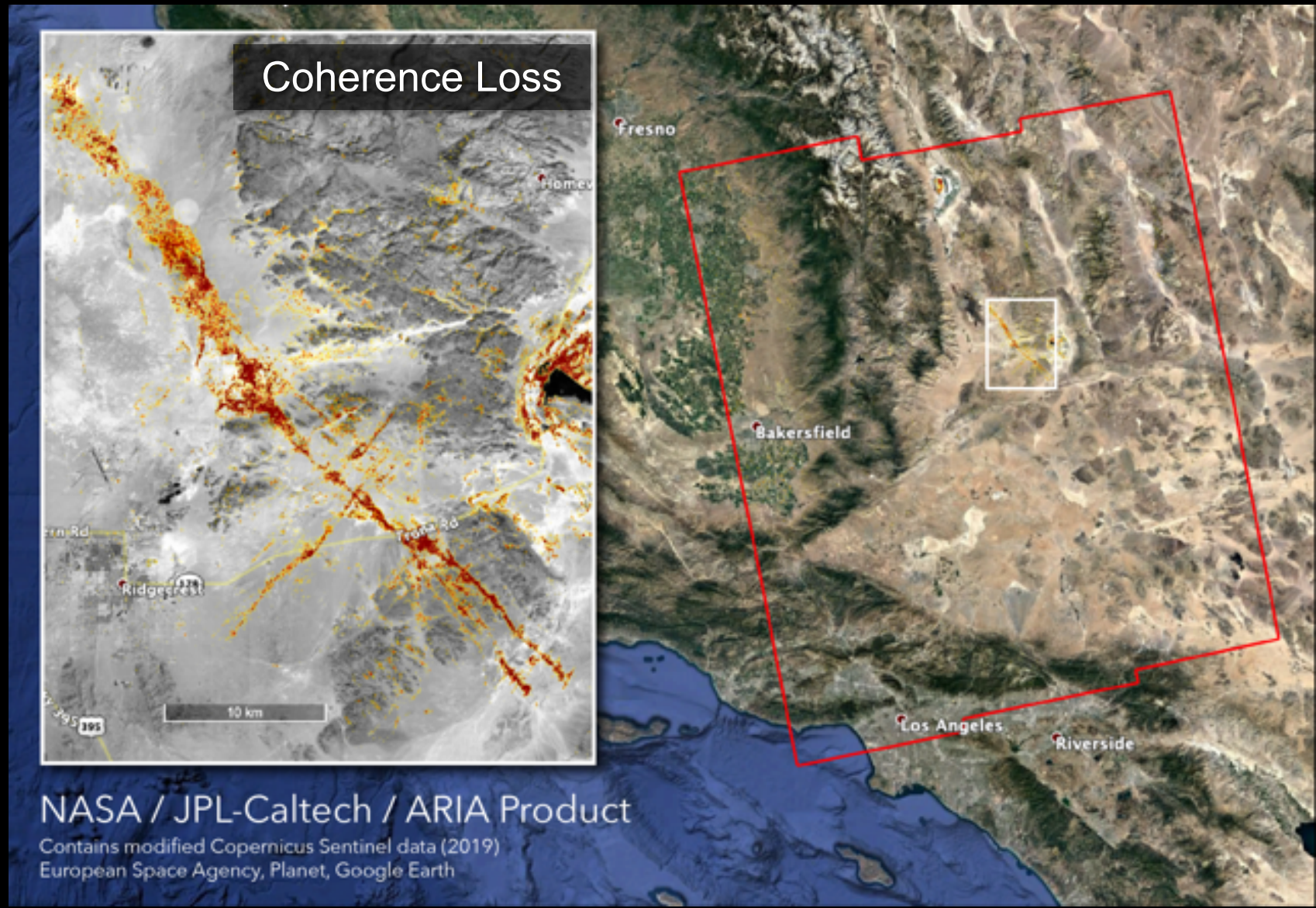
InSAR image: $c_1 c_2^* = A_1 A_2 e^{i(\varphi_1 - \varphi_2)}$

Coherence: $\frac{|\langle c_1 c_2^* \rangle|}{\sqrt{\langle c_1 c_1^* \rangle \langle c_2 c_2^* \rangle}}$

Los Angeles Times / NPR / UNAVCO Calendar



(Ross et al., *Science* 2019)

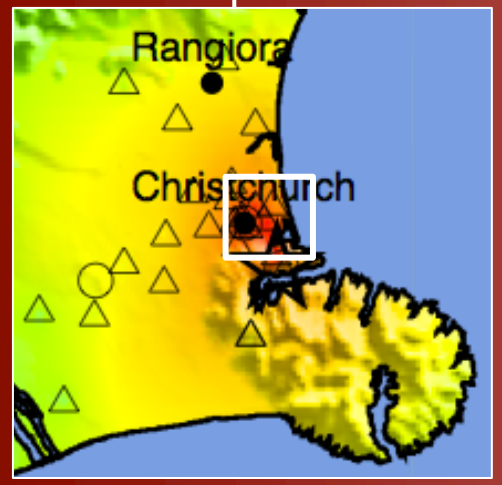


Feb 2011 Christchurch Earthquake Timeline

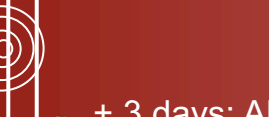
Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct

M6.3 Christchurch Earthquake

+ 20 min



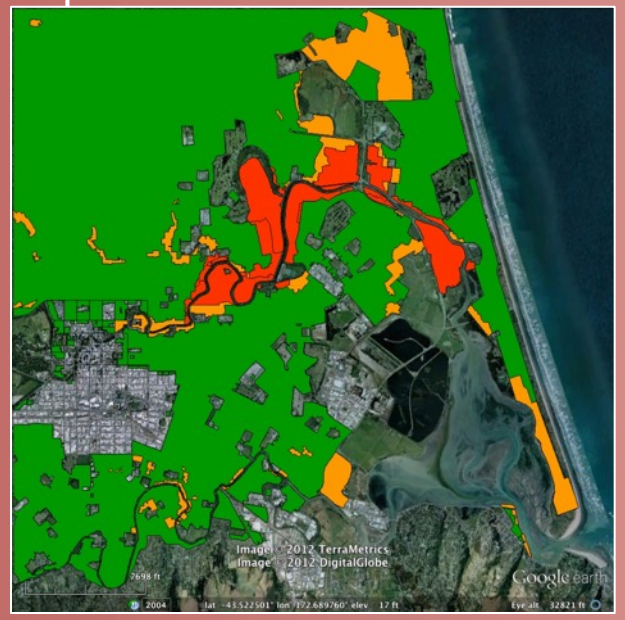
Multiple versions of Shakemap released (USGS NEIC)



+ 3 days: ALOS acquires data

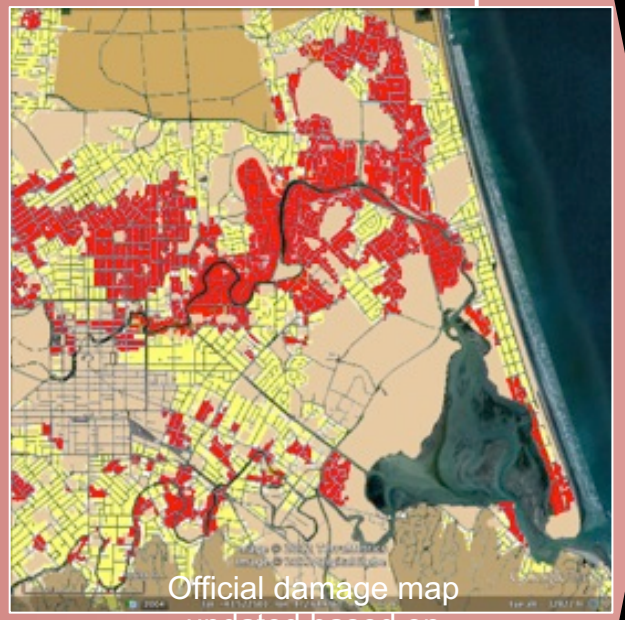
DPM from PALSAR data (ARIA)

+ 4 months



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

+ 8 months

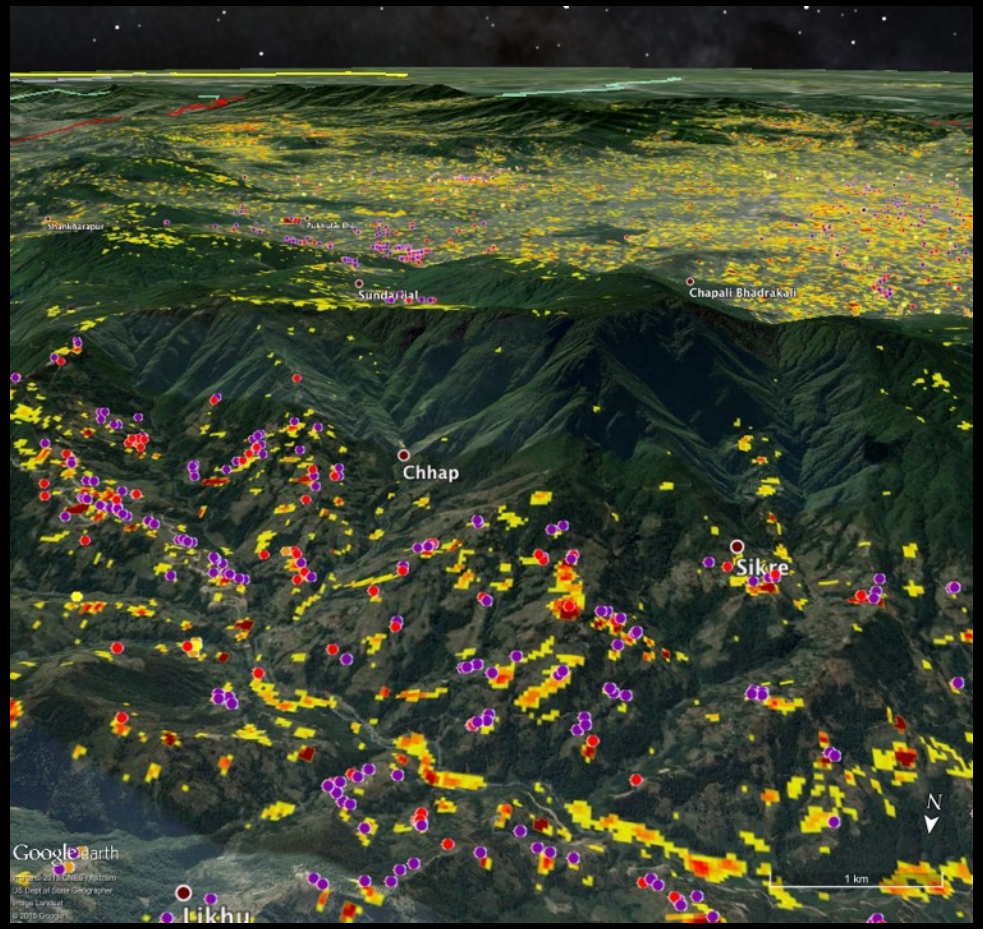


Official damage map updated based on ground observations (NZ Government)

Over 1000 buildings destroyed
185 people killed
US $30+ billion loss

Damage Proxy Map

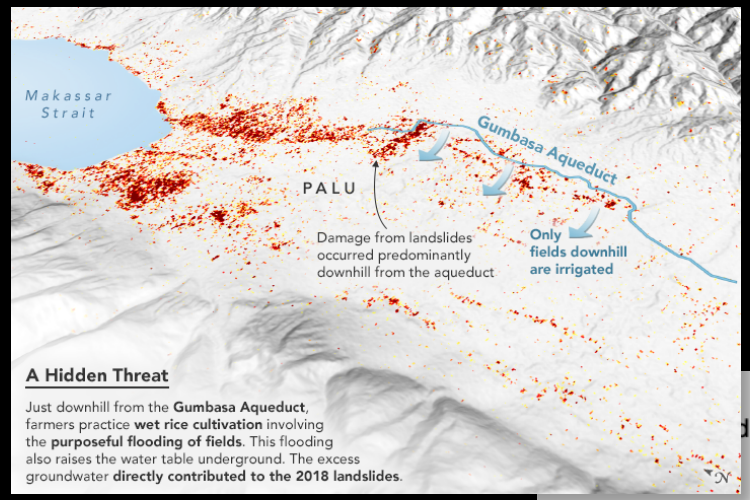
M7.8 2015 Gorkha Earthquake



(Yun et al., *SRL* 2015)

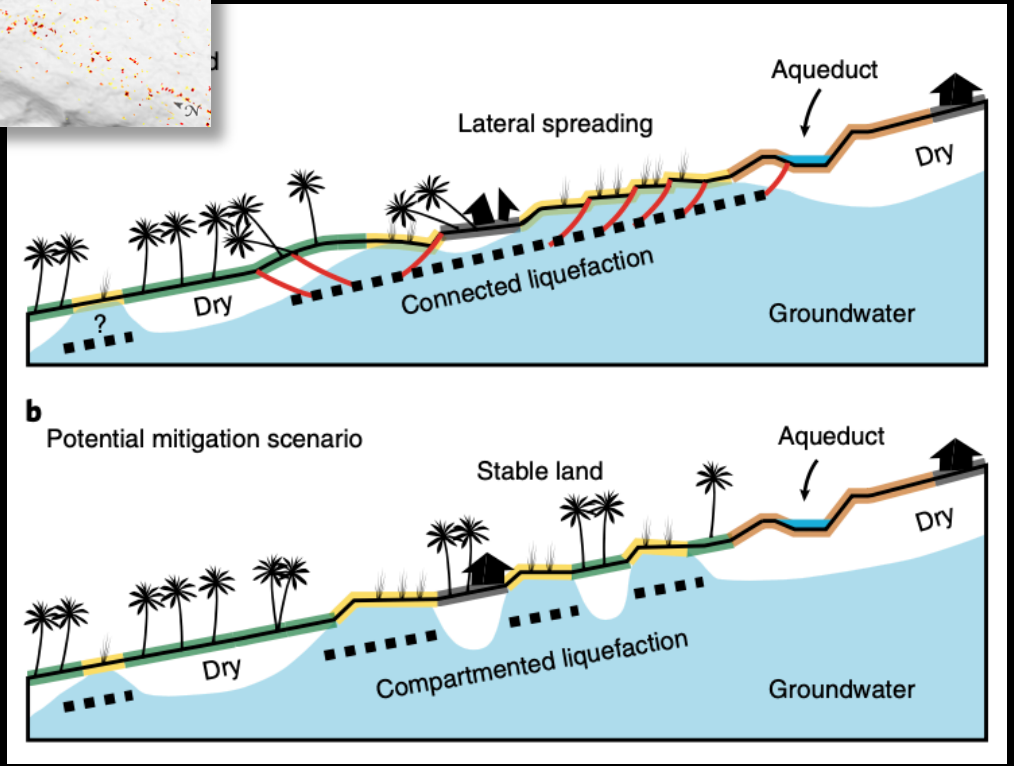
Jet Propulsion Laboratory
California Institute of Technology

Landsliding on a Very Gentle Slope (1º !)

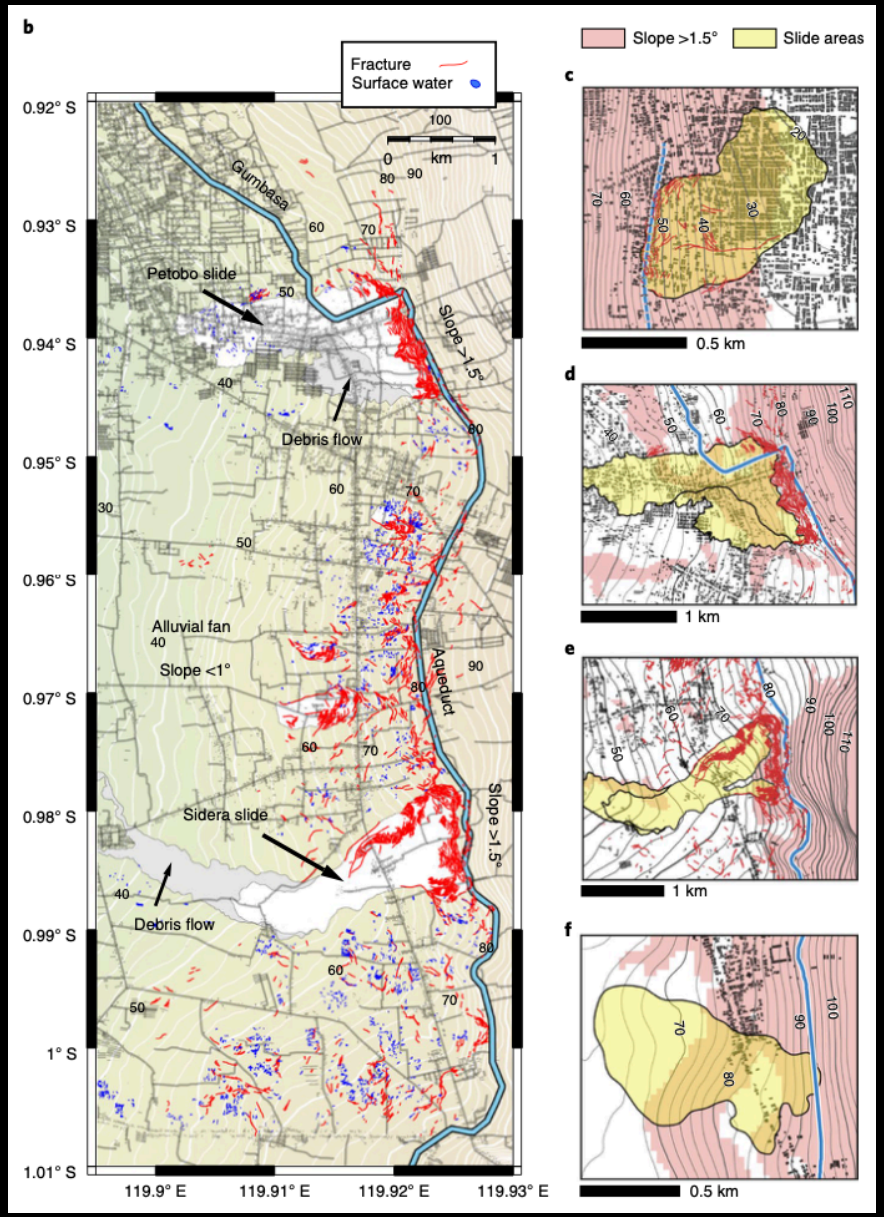


M7.5 September 28, 2018
Palu Earthquake

https://earthobservatory.nasa.gov/images/145796/palu-landslides-linked-to-rice-irrigation



Rapidly shared with the AHA center



(Bradley et al., *Nature Geoscience*, 2019)

EARTH OBSERVATORY OF SINGAPORE

Selected Customer Reviews

"For the historical center of Norcia, the damage zones from ARIA imaging (DPMs) compared well with damage maps obtained from on- ground surveys."

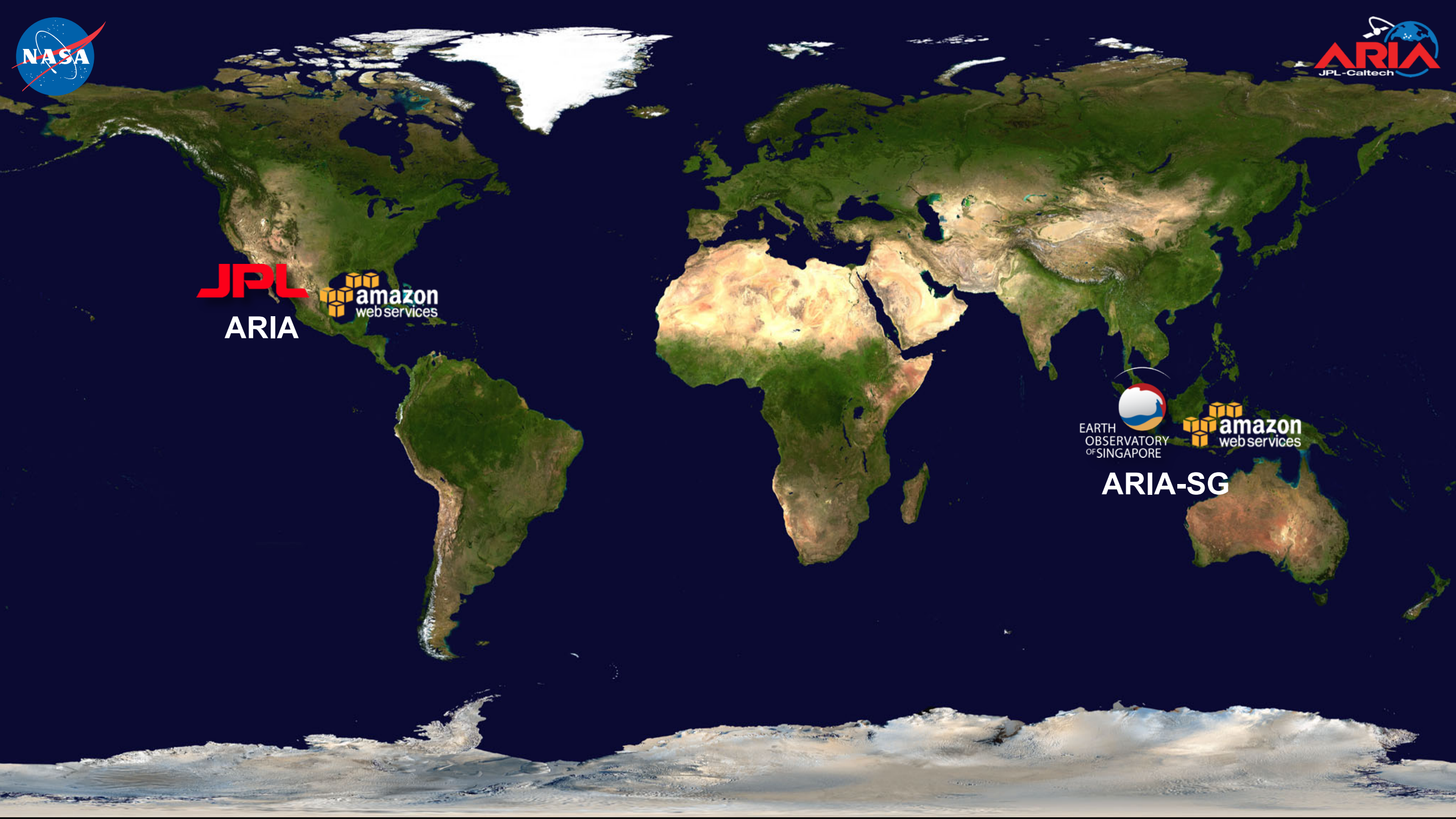
(Sextos et al., Earthquake Spectra 2018)
Outstanding Paper Award (NEC2020)

"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

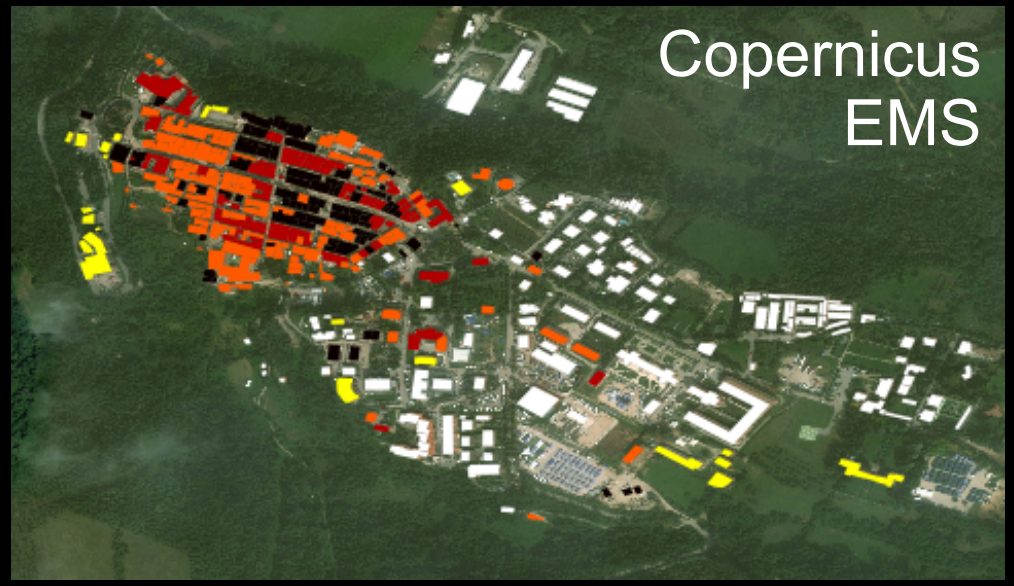
"It is so fascinating to see this map. The pattern of the distribution of red areas correlate with most realities on the ground."

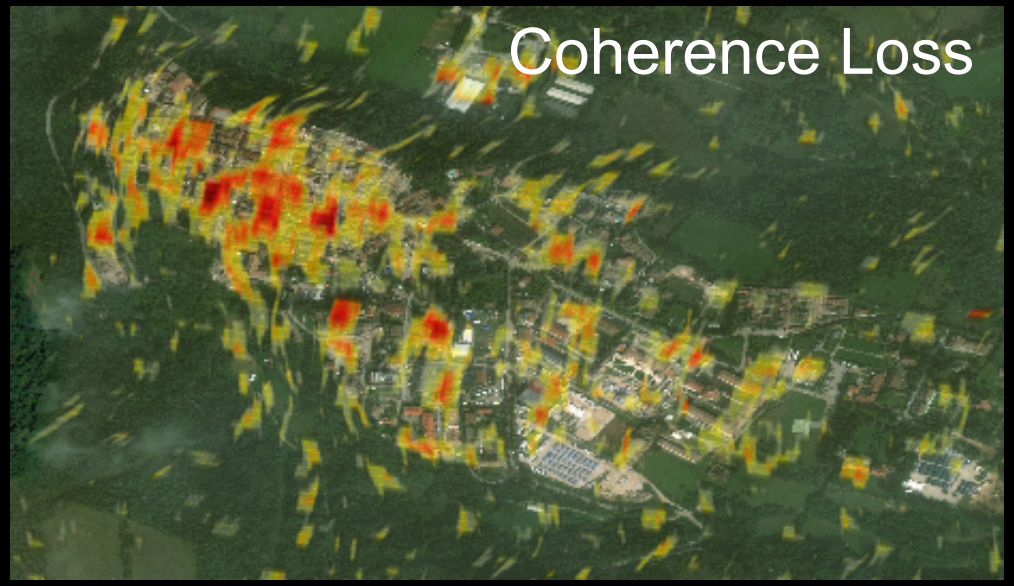
Indra Sharan, OFDA, USAID
From Nepal after the M7.8 2015 Gorkha Earthquake

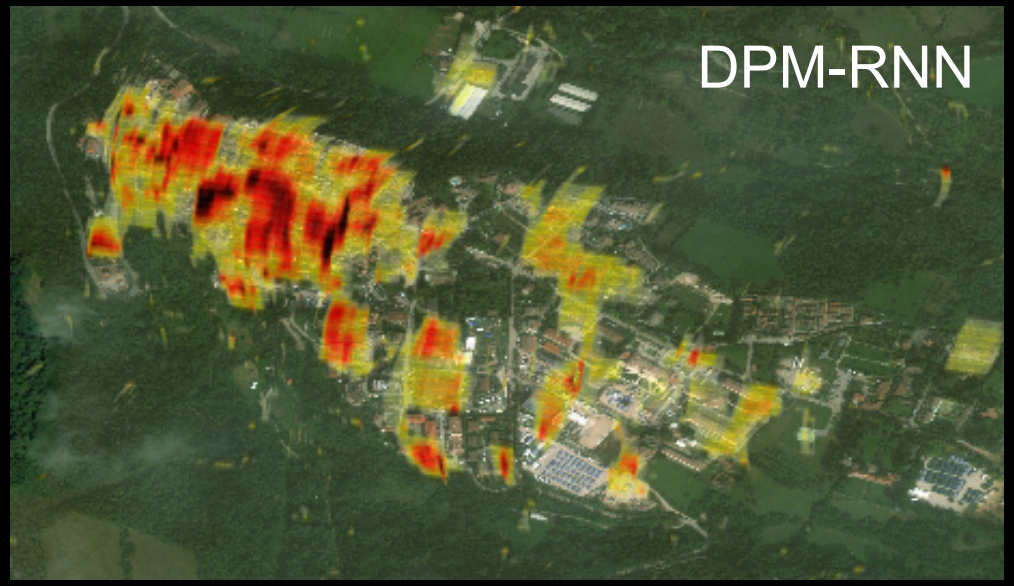

NASA
ARIA
JPL-Caltech
JPL
amazon web services
ARIA
EARTH OBSERVATORY OF SINGAPORE
amazon web services
ARIA-SG

DPM4: RNN

M6.2 2016 Amatrice Earthquake, Italy
Derived from Sentinel-1 SAR Data







(Stephenson et al, *TGRS*, in prep)

Oliver Stephenson (Caltech)

Tobias Köhne (Caltech)

Eric Zhan (Caltech)

Caltech

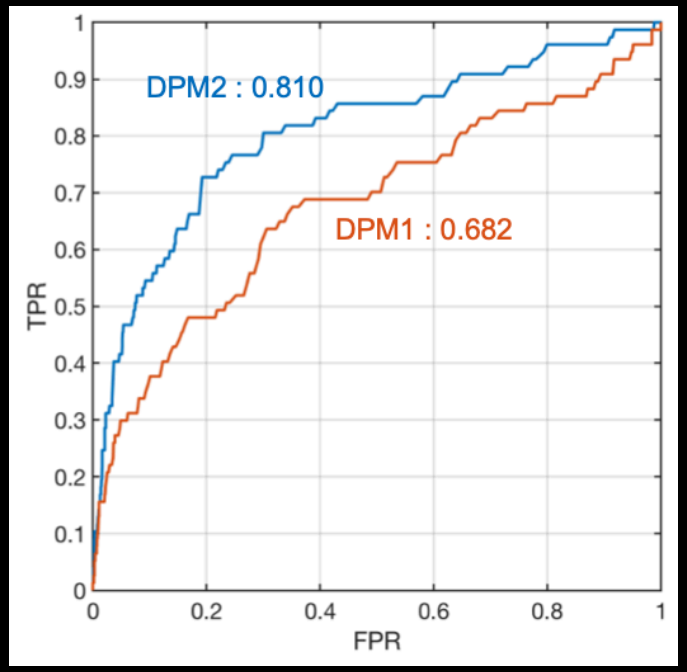
DPM2

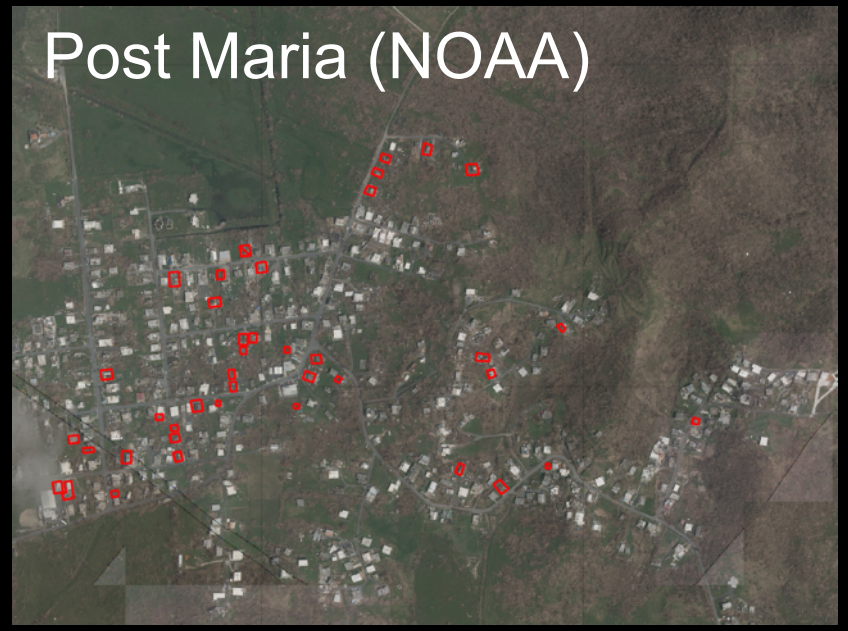
Multi-temporal Coherence

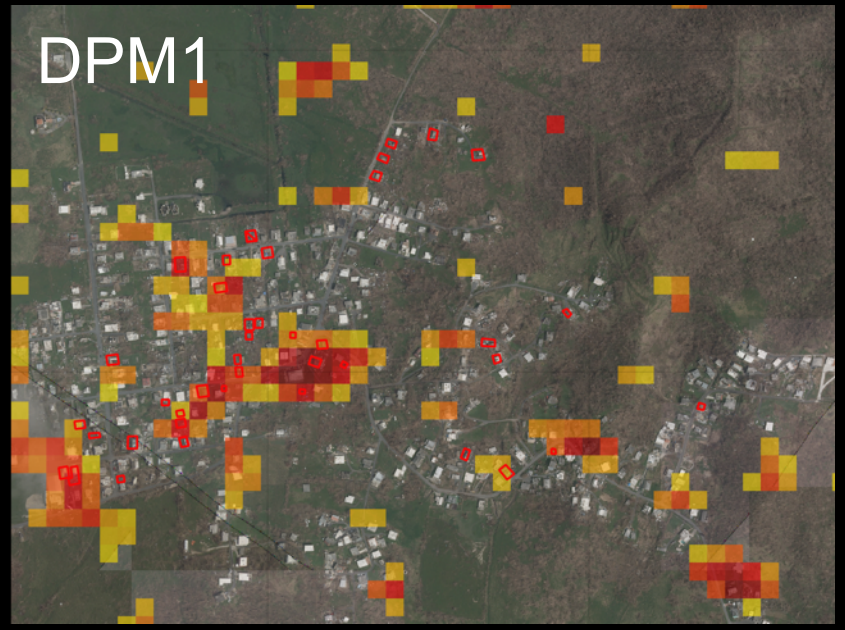
Puerto Rico
Hurricane Maria
Category 5, 2017

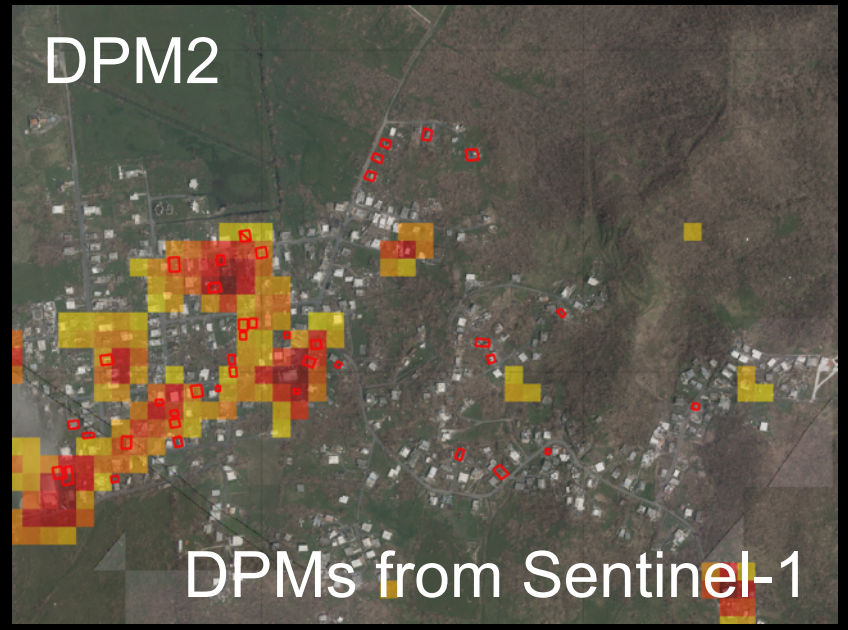
Jungkyo Jung
(JPL)

Method described in
(Jung et al., *TGRS* 2018)





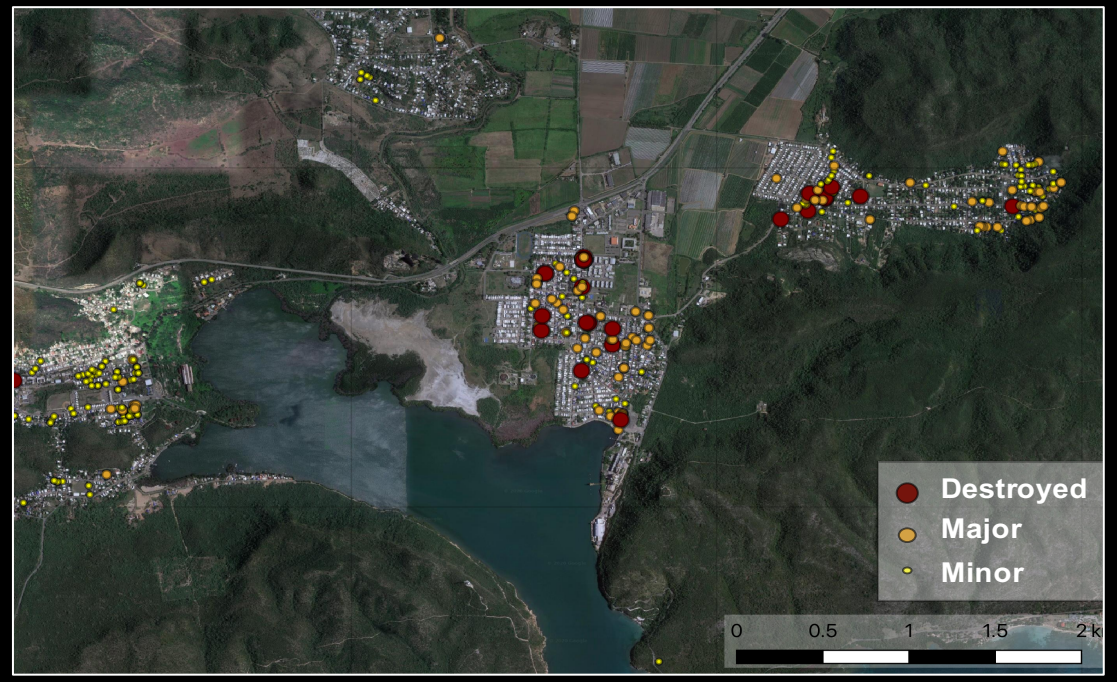




M6.4 Jan 2020 Puerto Rico Earthquake

DPM2, for the first time in response mode

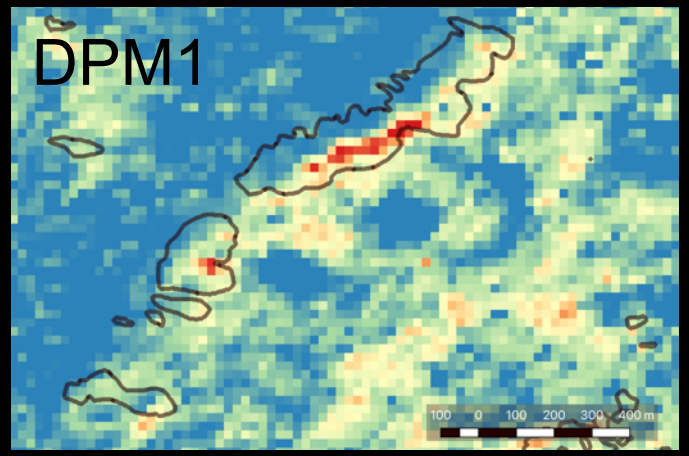
Ground Truth (CAP) for Building Damage

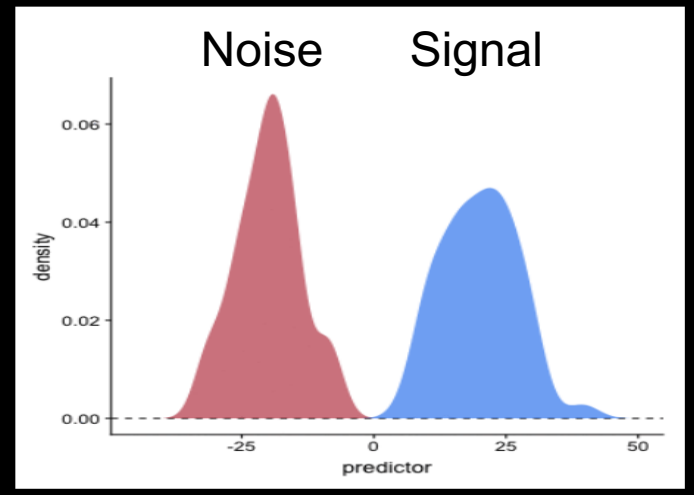


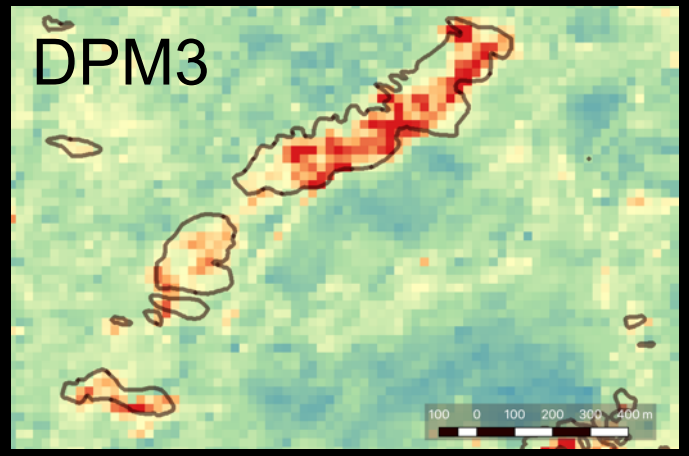
Jet Propulsion Laboratory
California Institute of Technology

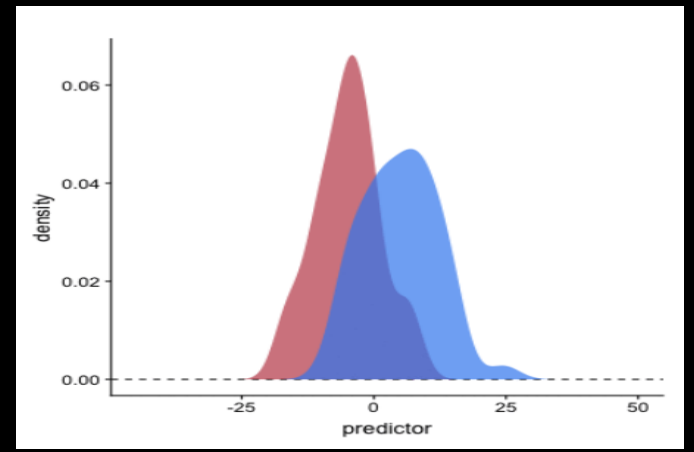
DPMs of Landslides, Hokkaido, Japan

Triggered by the M6.6 Hokkaido Earthquake (Sept 2018)



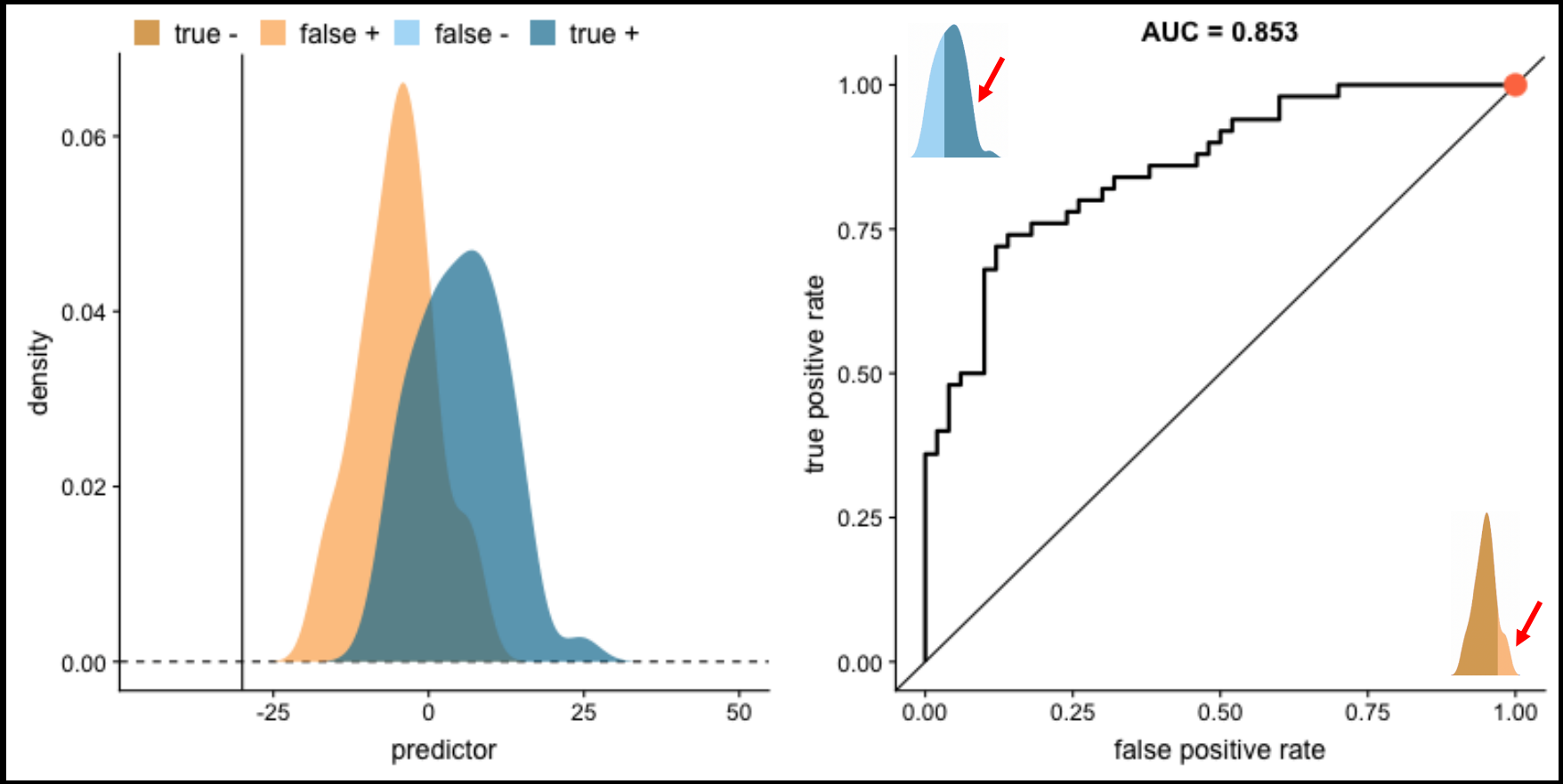






DPMs from ALOS-2

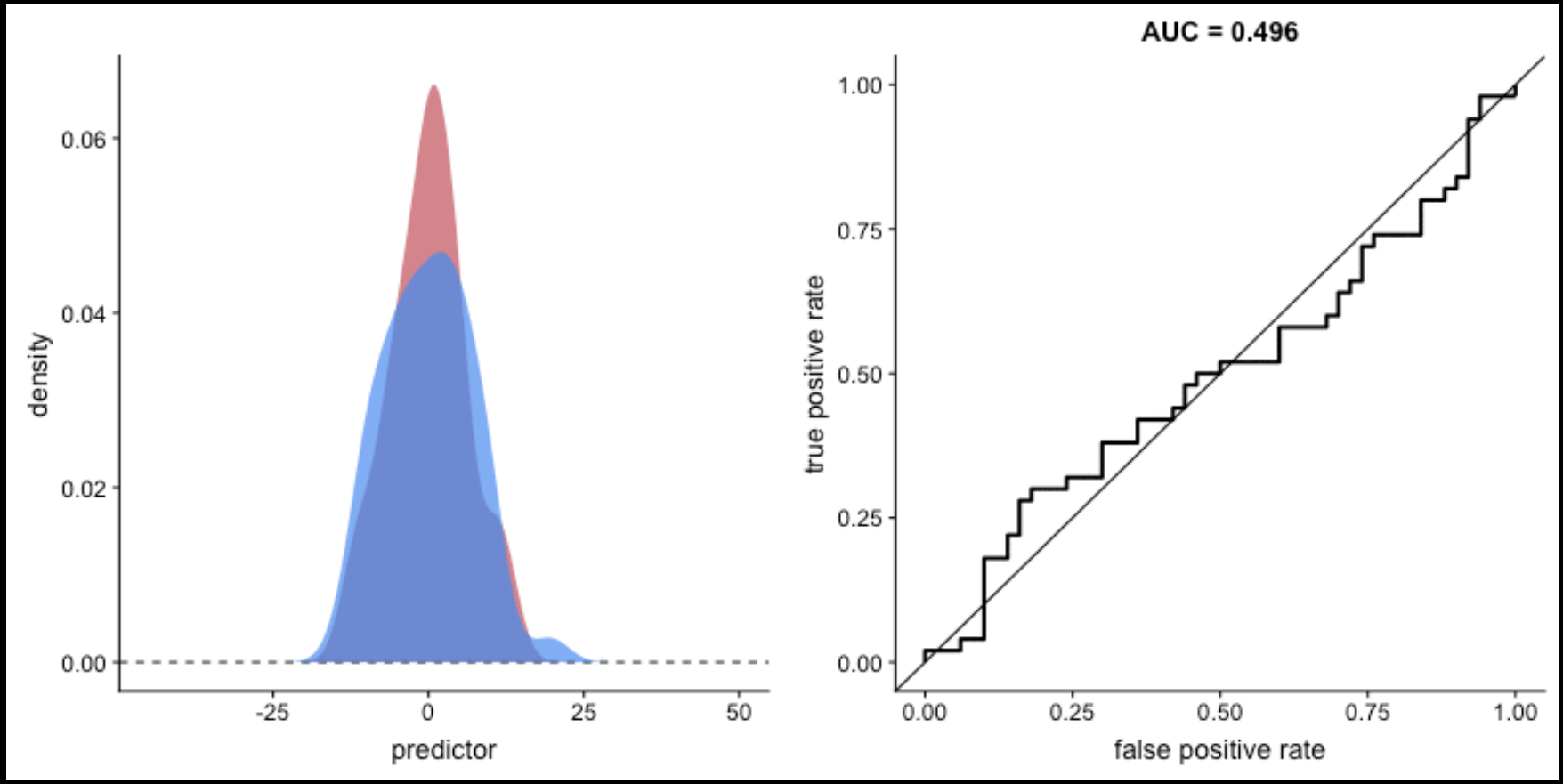
ROC (Receiver Operating Characteristic) Curve



Created by Dariya Sydykova

https://github.com/dariyasydykova/open_projects/tree/master/ROC_animation

AUC (Area Under Curve)



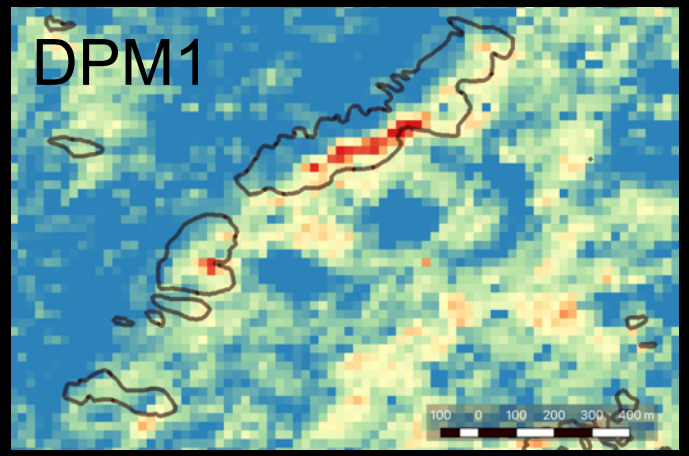
Created by Dariya Sydykova

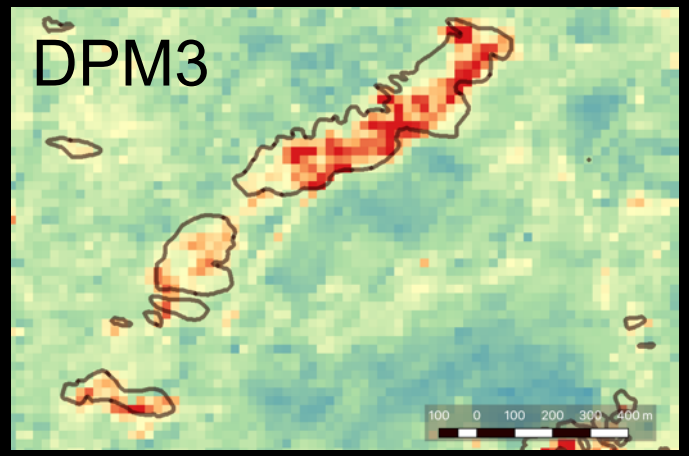
https://github.com/dariyasydykova/open_projects/tree/master/ROC_animation

DPMs of Landslides, Hokkaido, Japan

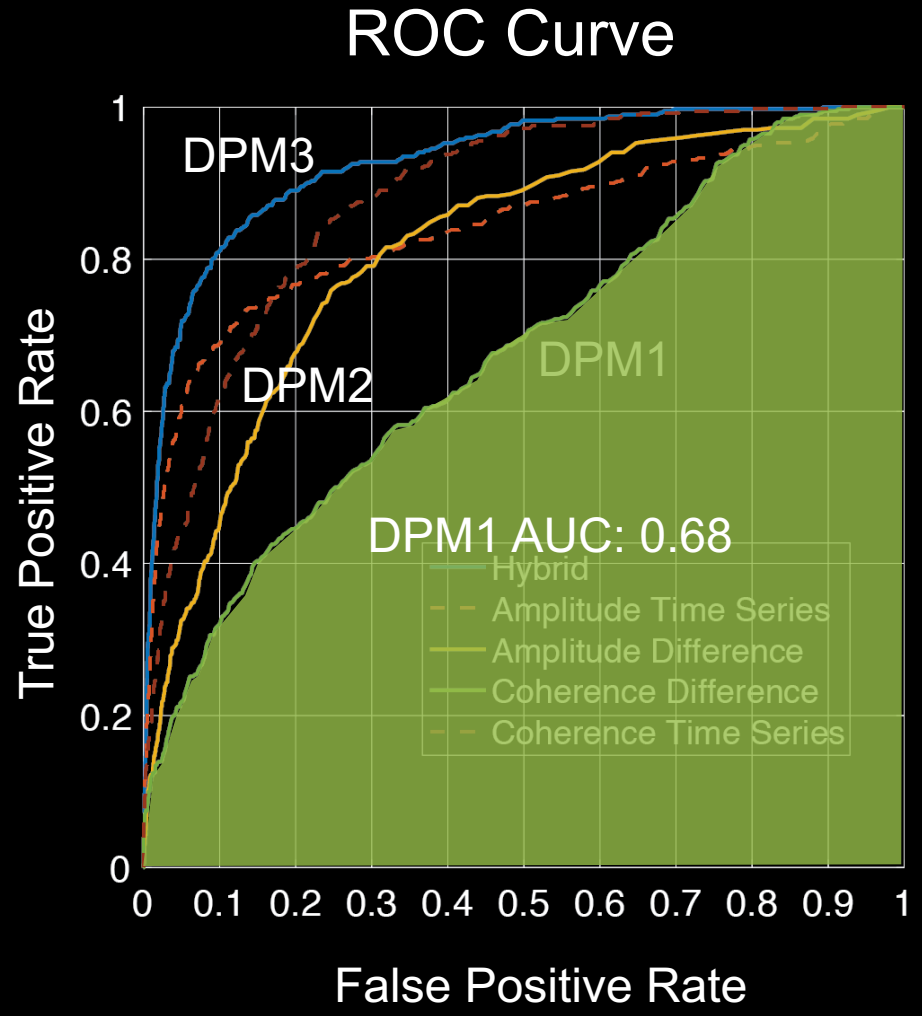
Triggered by the M6.6 Hokkaido Earthquake (Sept 2018)

Jet Propulsion Laboratory
California Institute of Technology





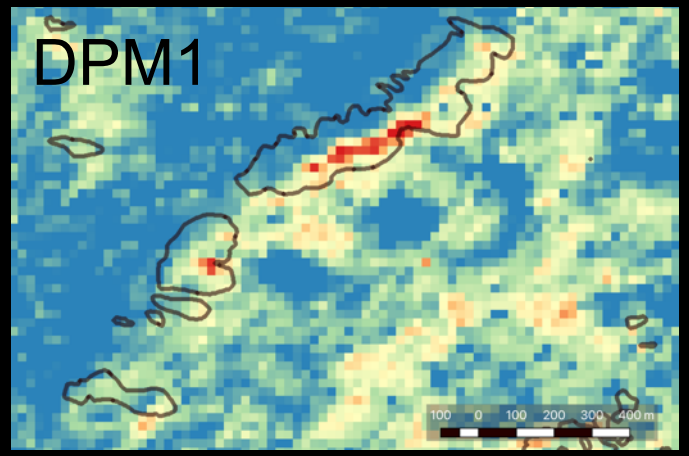
DPMs from ALOS-2

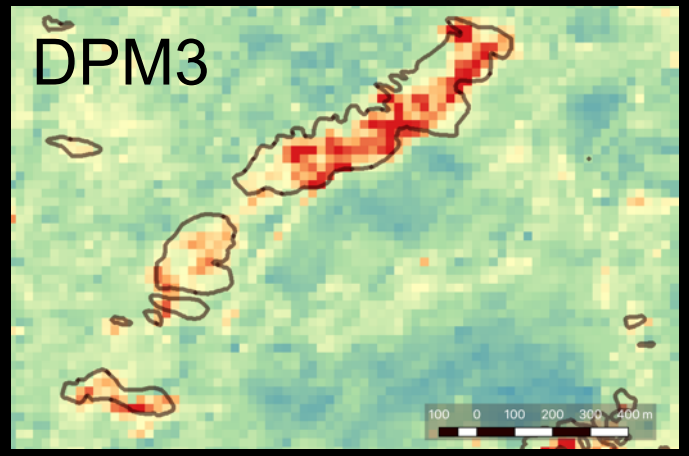


DPMs of Landslides, Hokkaido, Japan

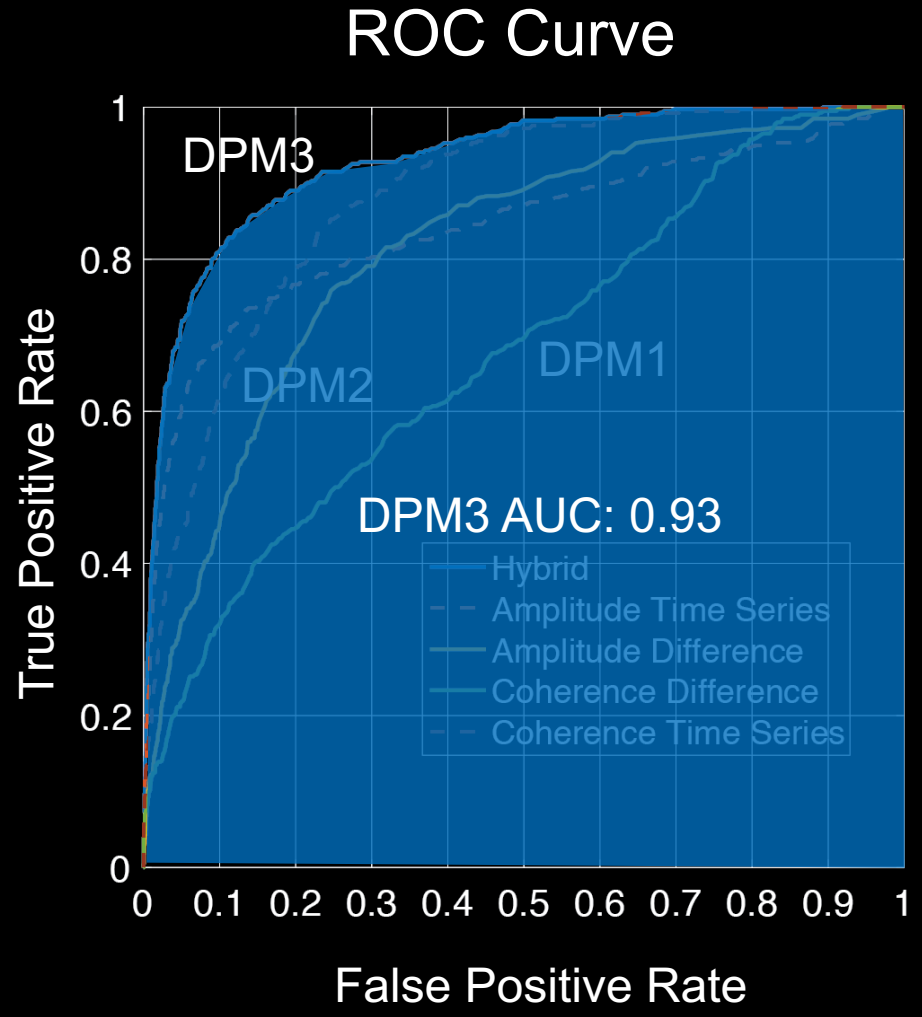
Triggered by the M6.6 Hokkaido Earthquake (Sept 2018)

Jet Propulsion Laboratory
California Institute of Technology





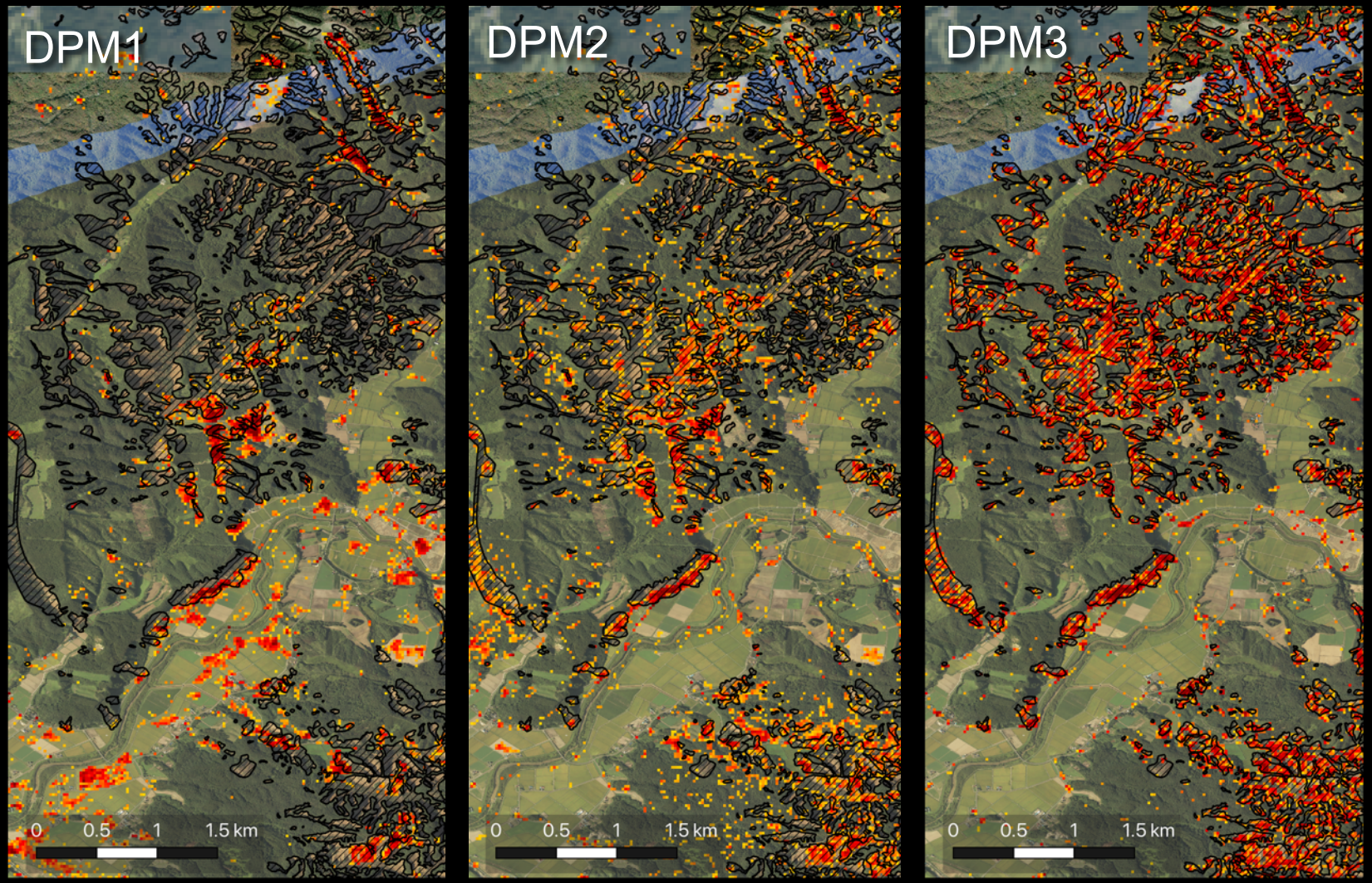
DPMs from ALOS-2

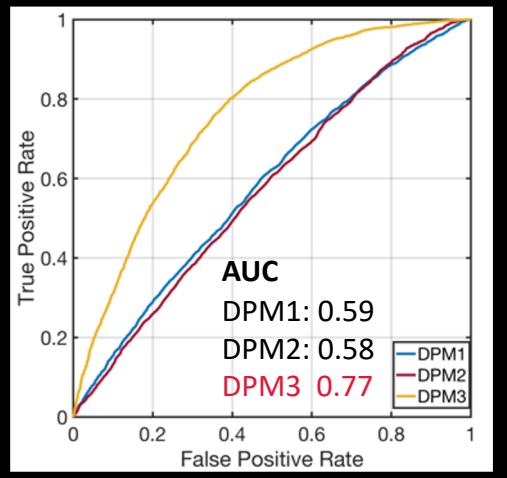


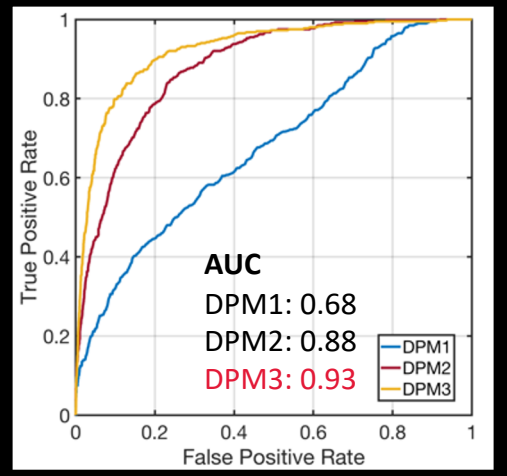
DPMs from Multitemporal SAR Analysis

M6.6 Sep 2018 Hokkaido Earthquake-Induced Landslides

Jet Propulsion Laboratory
California Institute of Technology

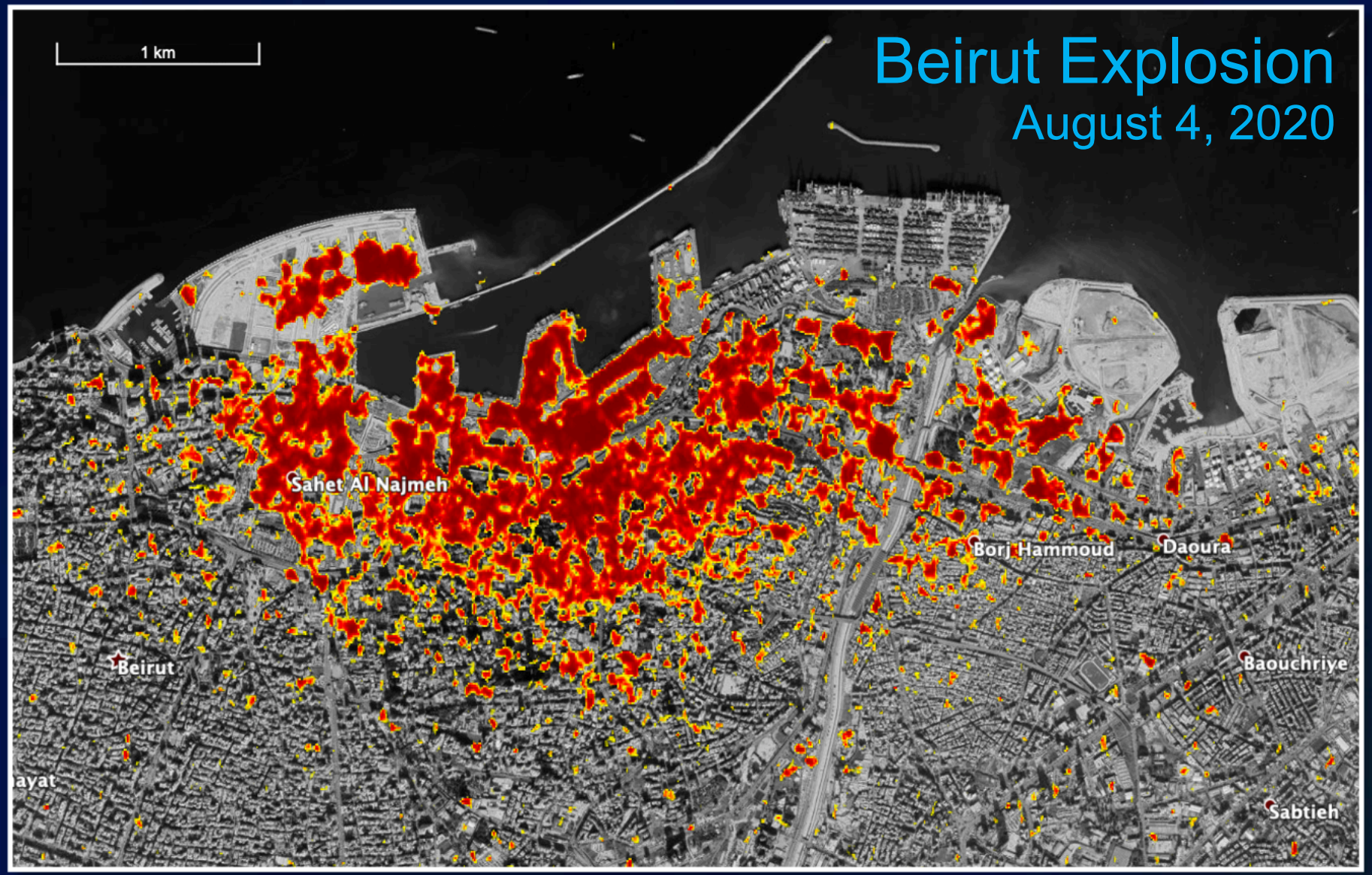




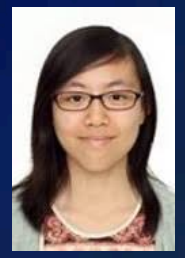


DPMs from ALOS-2, Black polygons by GSI

(Jung & Yun, *Remote Sensing*, 2019)



Jungkyo Jung
(JPL)



Cheryl Tay
(NTU)

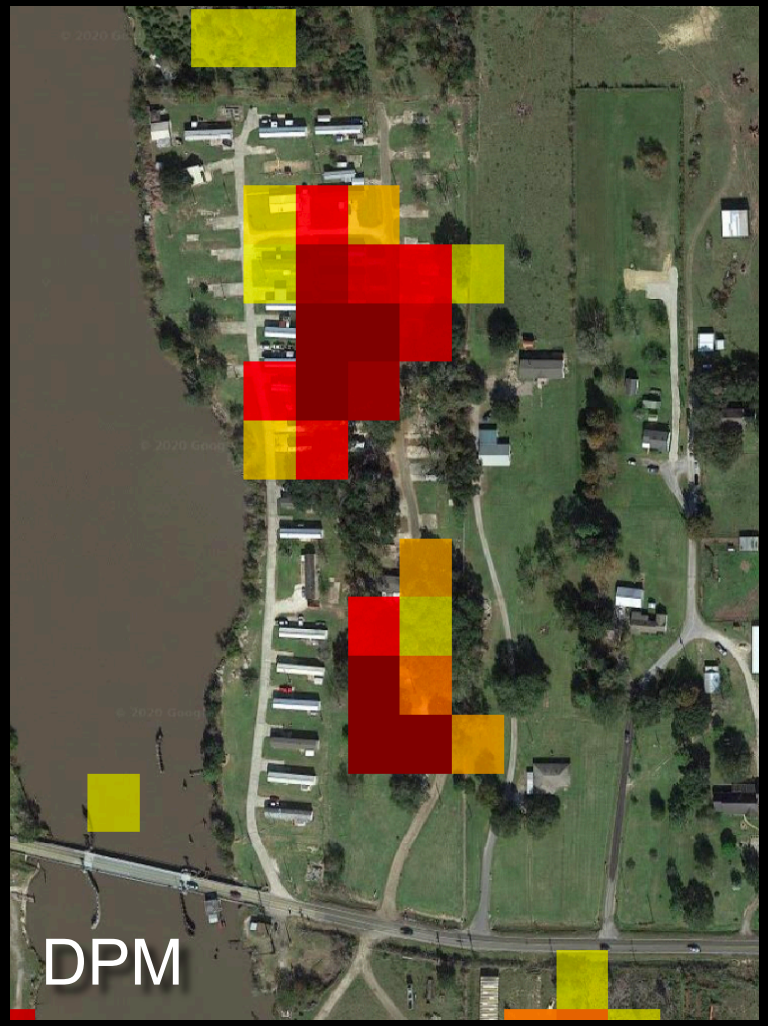
Emma Hill
(NTU)

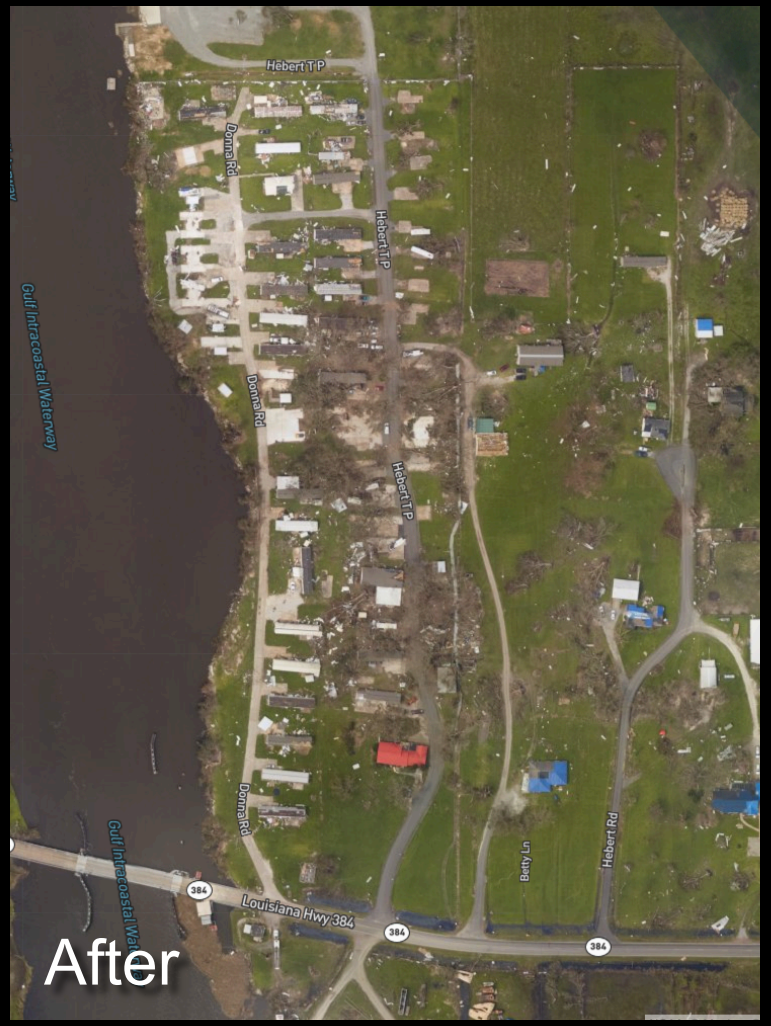
NASA / JPL-Caltech / ARIA / EOS Product

Contains modified Copernicus Sentinel data (2020)

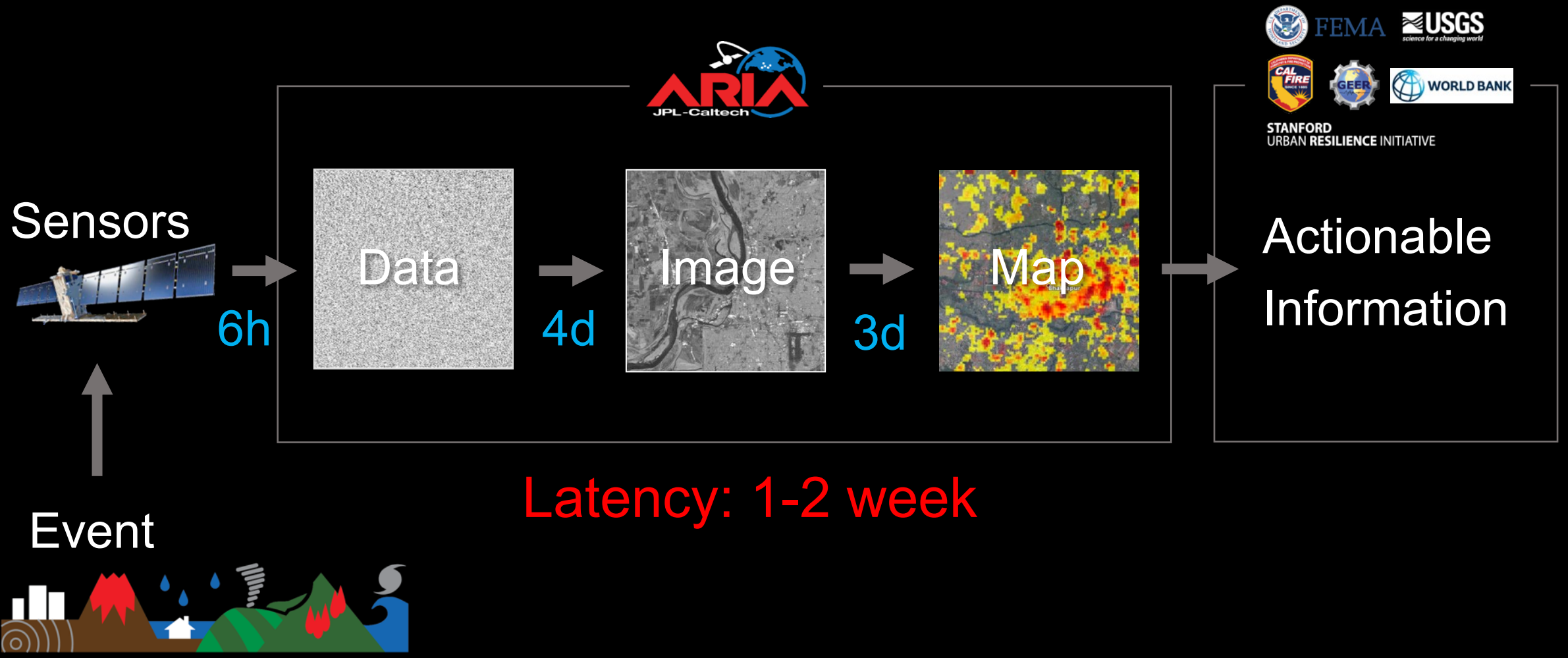
Basemap: Google, Landsat, Copernicus

Hurricane Laura Damage in Cameron, LA





Multi-Temporal SAR-based DPM Production Time (Serial Processing)



Multi-Temporal SAR-based DPM Production Time (Parallel Processing)

Sensors

6h

Data

8h

Image

4h

Map

Actionable Information

Event

Latency: 18h


Alex Torres (JPL)


Shi Tong Chin (NTU)


Hook Hua (JPL)


Gerald Manipon (JPL)

Do these appear similar in color?

Color blindness (color vision deficiency, or CVD) affects approximately 1 in 12 men (8%) and 1 in 200 women (0.5%) in the world.

More than 99 in 100 (99%) of all color blind people have a red-green color vision deficiency (Deuteranopia).

Source: https://www.color-blindness.com/deuteranopia-red-green-color-blindness/

DPM Colormap for Deuteranope

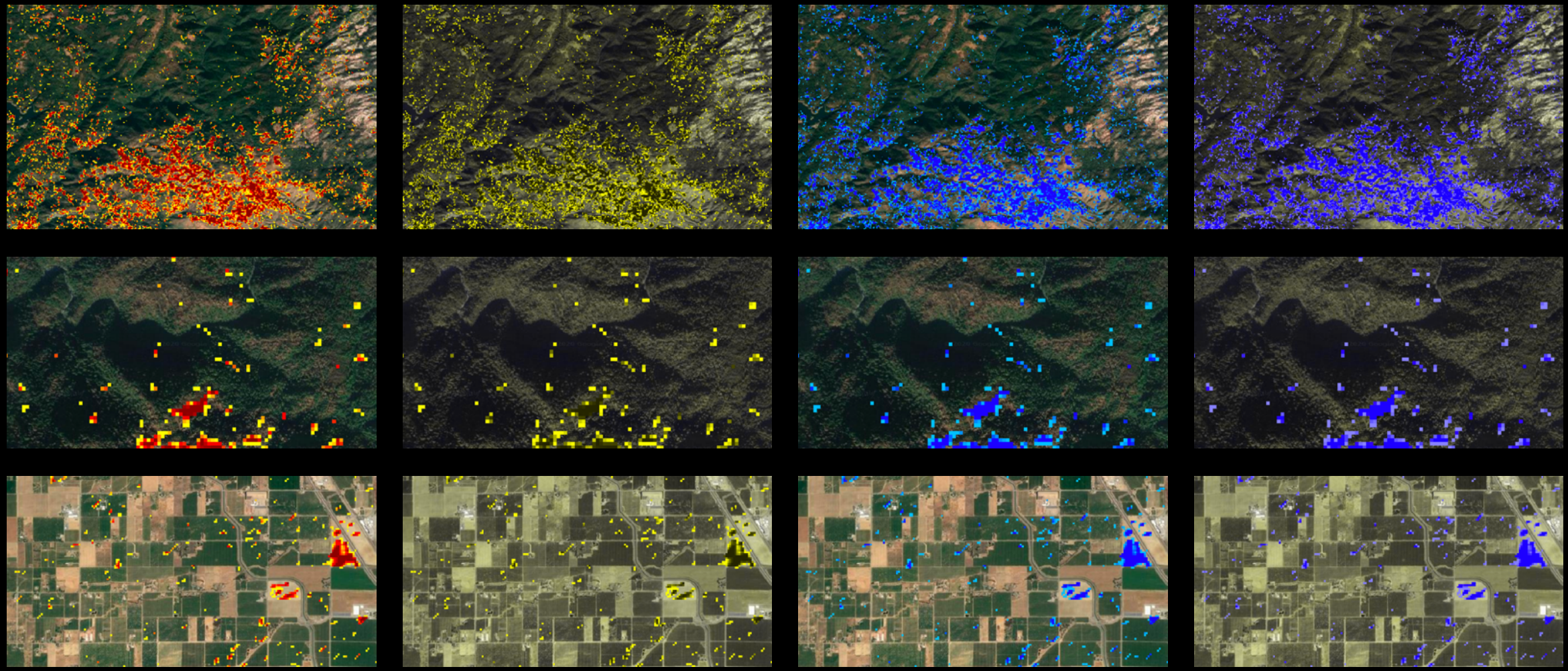
Cheryl Tay
(NTU)

Original

Deuteranopia

CVD-friendly

Deuteranopia



COVID-19 Response Project

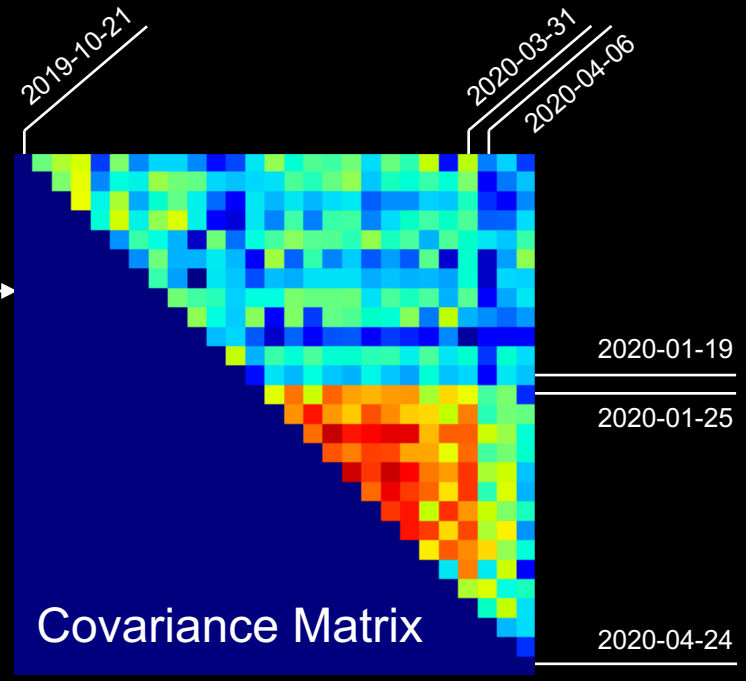
Shanghai, China

2 km

Construction Pace Monitoring

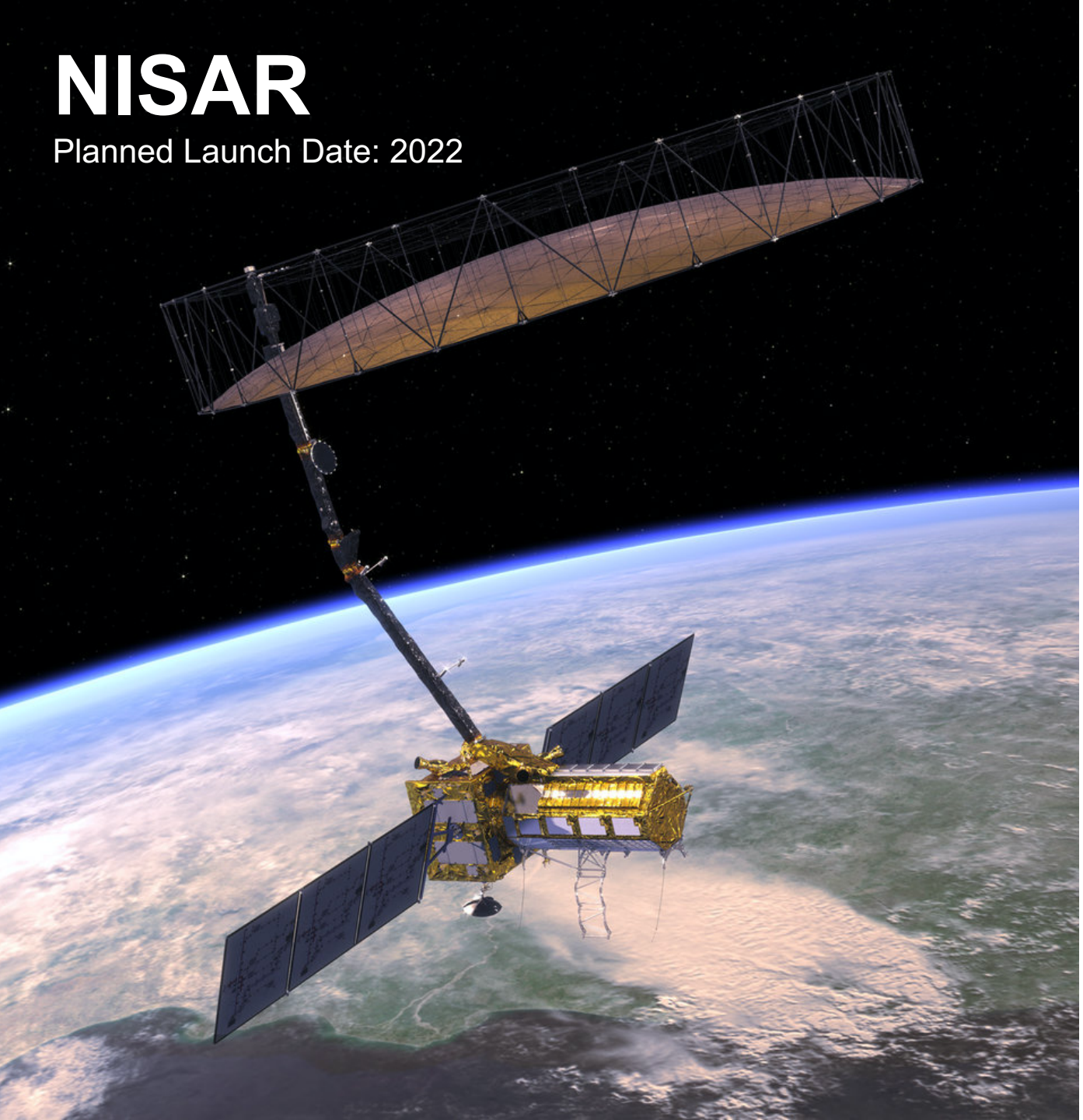
(Economy Slowdown due to COVID-19 Lockdown)

- Construction stopped between Jan 19 and Jan 25. (Note: the lockdown was placed on Jan 23)
- Construction resumed between Mar 31 and Apr 6. (appears more gradual than the lockdown)
- Also useful for post-disaster recovery monitoring → Post-Disaster Needs Assessment (PDNA)



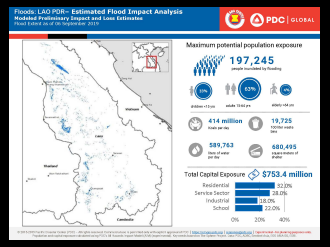
NISAR

Planned Launch Date: 2022



Mission Characteristics

Orbit Altitude	747 km
Orbit Inclination	98.4°
Repeat Cycle	12 days
Time of Nodal Crossing	6 AM/ 6 PM
Orbit Control	< 500 m
Pointing Control	< 273 arcsec
Pointing	Left (south)
L/S Duty Cycle	> 50%/10%
Baseline Mission Duration	3 years
Consumables	5 years
Data and Product Access	Free & open
Wavelength	L-band: 24 cm S-band: 9 cm
SAR Resolution	3–10 m mode-dependent



Source: AHA Centre

Summary

Flood/Damage mapping algorithms/systems are being matured at JPL (California) and EOS (Singapore). We are producing FPM2 (probability of flood) and DPM2 (probability of damage) in support of rapid disaster response.

DPMs (KMZ, GeoTIFF) now come with a CVD-friendly palette too.

Similar methods can be used to monitor slowly occurring changes such as post-disaster recovery or COVID-19 induced human activity slowdown.

NISAR will observe Earth's land and ice-covered surfaces globally with 12-day regularity on ascending and descending passes, sampling Earth on average every 6 days for a baseline 3-year mission (~85TB products per day)

ARIA JPL-Caltech | NASA | Jet Propulsion Laboratory, California Institute of Technology | Earth Observatory of Singapore | Caltech | NASA Earth Science DISASTERS PROGRAM

Product access: aria-share.jpl.nasa.gov
ariasg-products.earthobservatory.sg
Email: shyun@jpl.nasa.gov