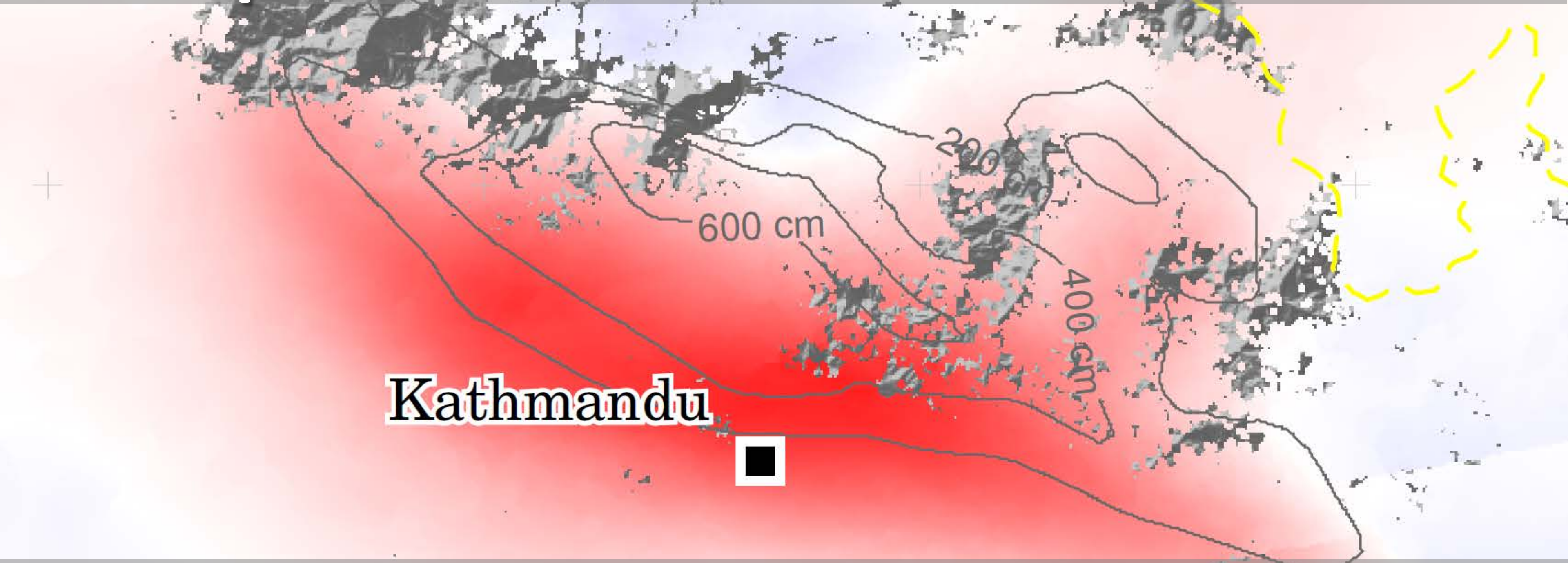
Monitoring our Dynamic, Hazardous planet with Earth Observation



Tim J Wright

COMET, School of Earth and Environment, University of Leeds

NERC SCIENCE OF THE ENVIRONMENT

Earthquakes without Frontiers

COMET

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@EwFProject

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Thanks to…

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Juliet Biggs; **COMET/Bristol**
Hua Wang; **now at Guangdong University of Technology**
Matt Garthwaite**; now at Geoscience Australia**
Tadashi Yamasaki; **now at GSI Japan**
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Vicki Stevens; **Caltech**
James Hollingsworth; **ARUP**
Mike Poland; **Cascades Volcano Observatory, USGS**

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Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics

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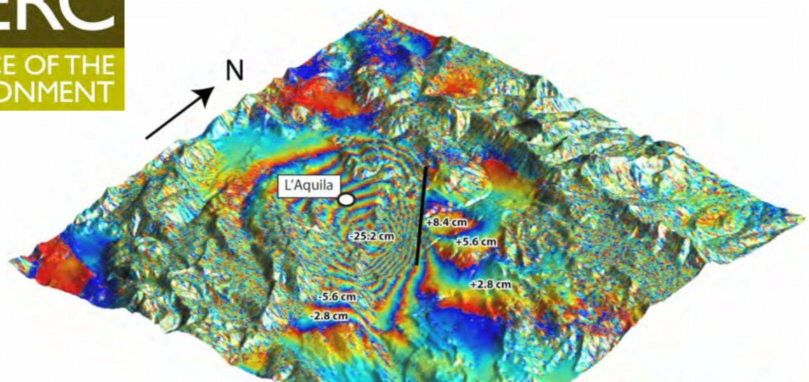
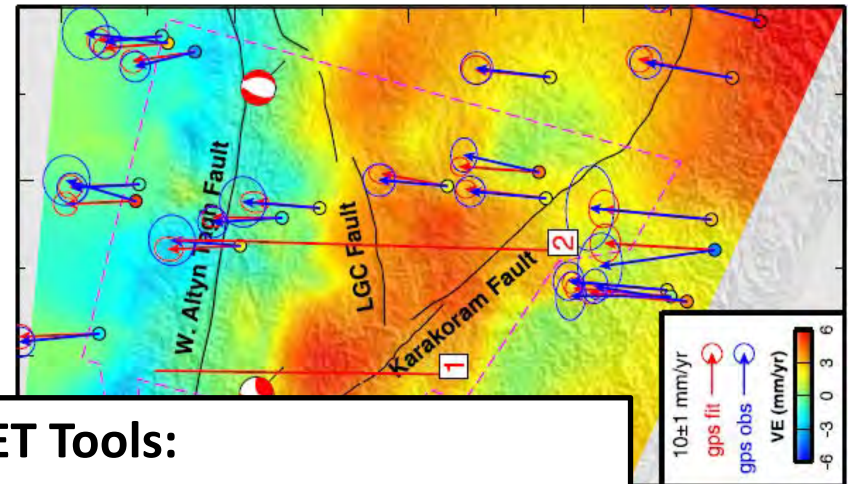
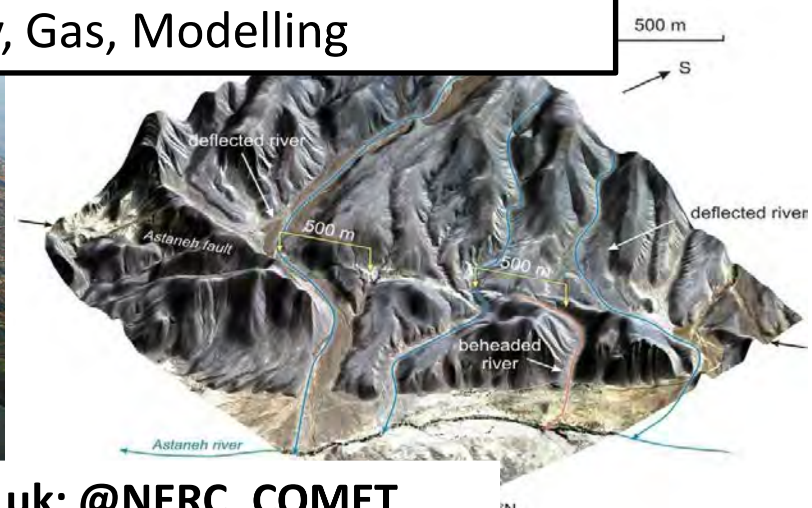




COMET Tools:
InSAR, GPS, Seismology, Geology, Geomorphology, Geochronology, Gas, Modelling



http://comet.nerc.ac.uk; @NERC_COMET

Interdisciplinary partnership between Universities of Leeds, Oxford, Cambridge, UCL, Reading, Bristol, Newcastle, Durham, Liverpool and BGS to exploit Earth Observation data for Geohazards

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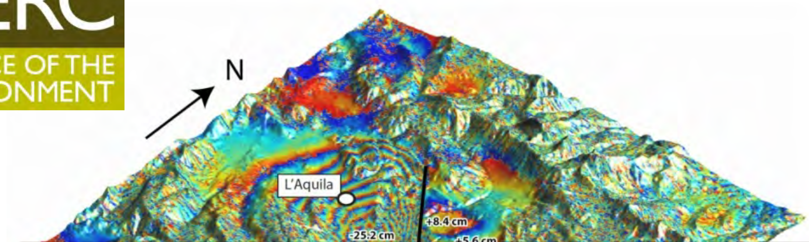
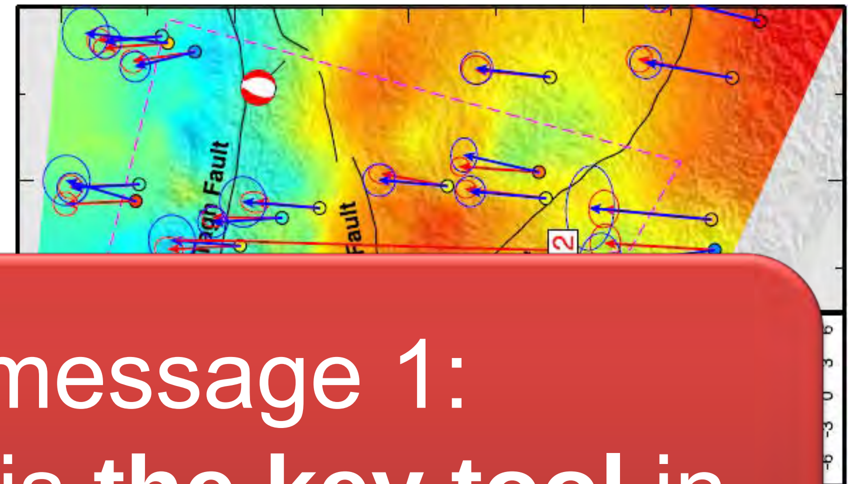
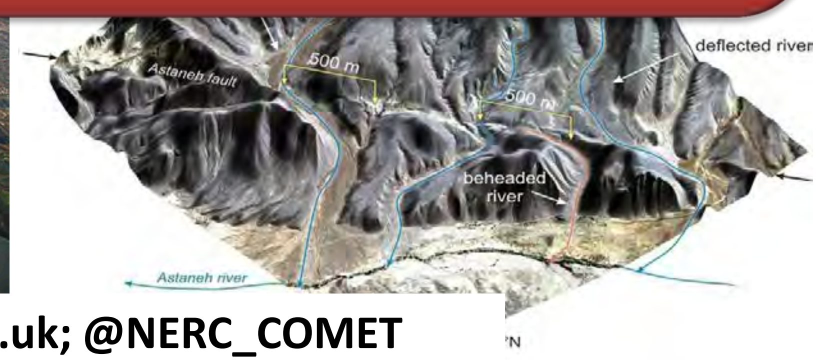




Take home message 1:
Earth observation is **the key tool** in understanding our hazardous planet.



http://comet.nerc.ac.uk; @NERC_COMET

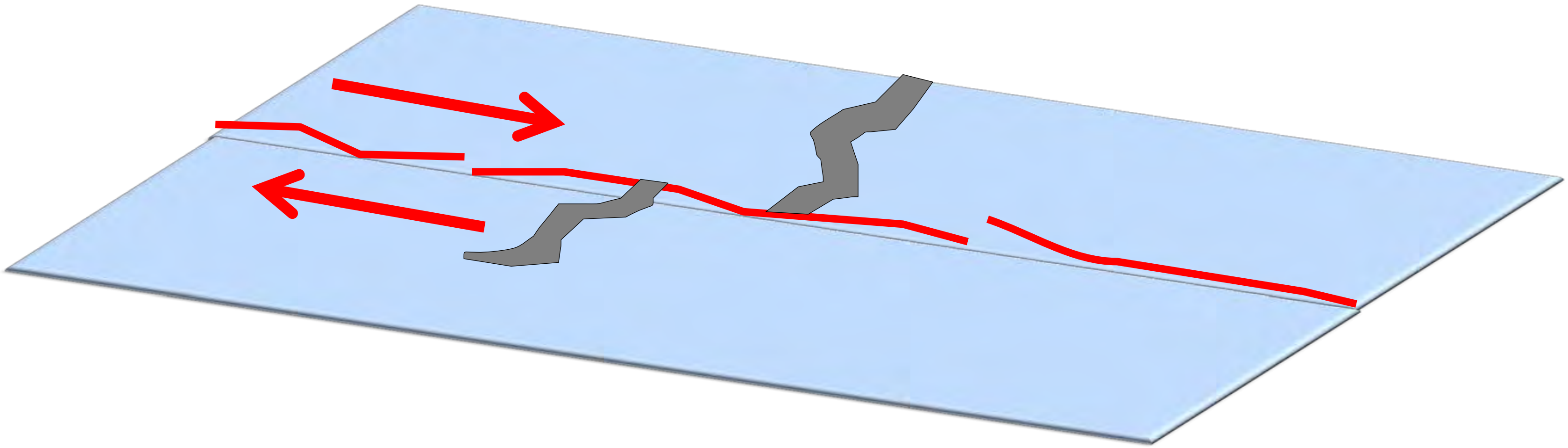
Interdisciplinary partnership between Universities of Leeds, Oxford, Cambridge, UCL, Reading, Bristol, Newcastle, Durham, Liverpool and BGS to exploit Earth Observation data for Geohazards


Take home message 2:
EO tools need to be integrated into the standard kitbag of every geologist, volcanologist, seismologist…

Q. When is the next big one?

Need to know:

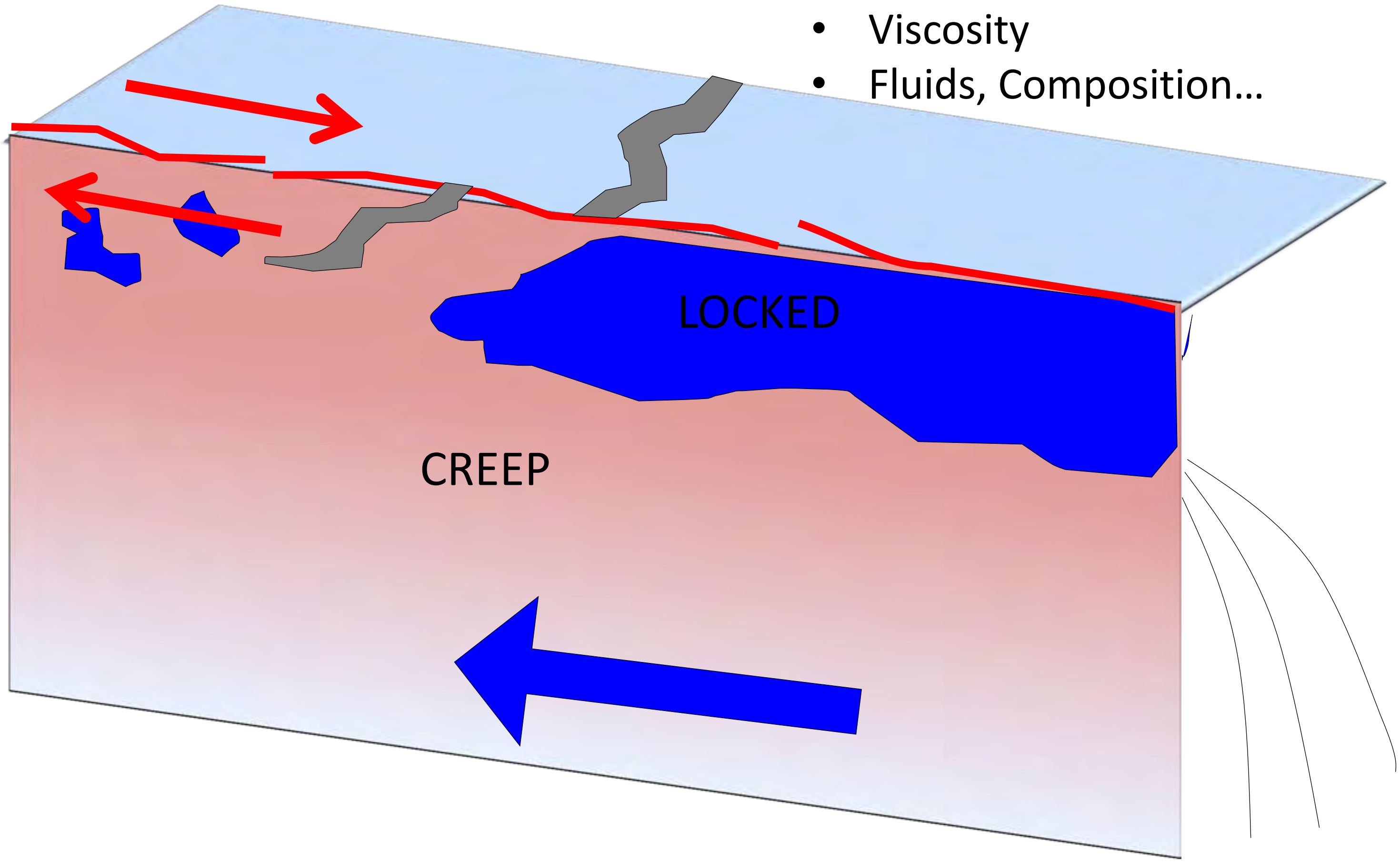
- Slip rate
- Size/date of previous earthquakes
- Locked or creeping (friction)



Q. When is the next big one?

Need to know:

- Slip rate
- Size/date of previous earthquakes
- Locked or creeping (friction)
- Temperature
- Viscosity
- Fluids, Composition…



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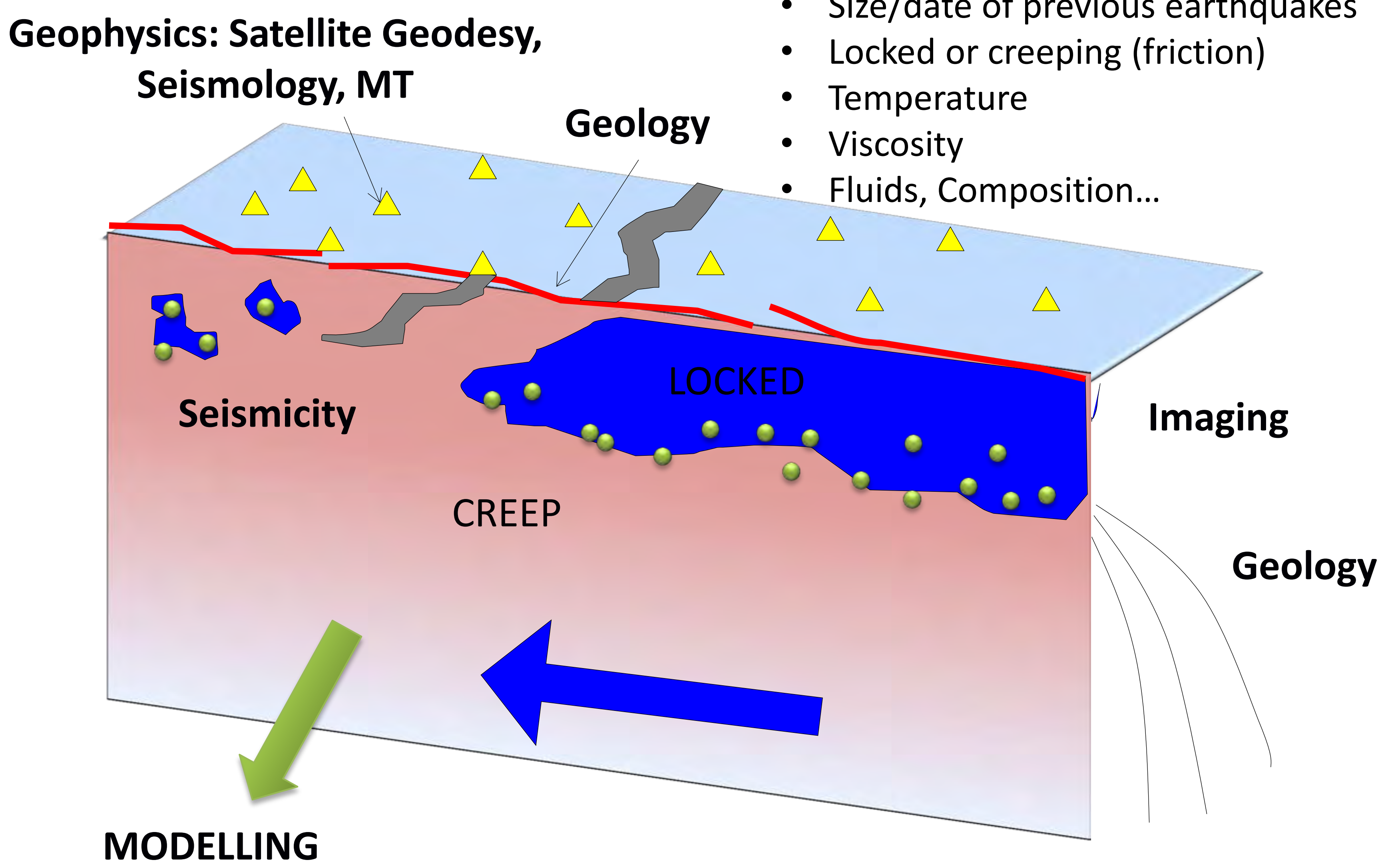
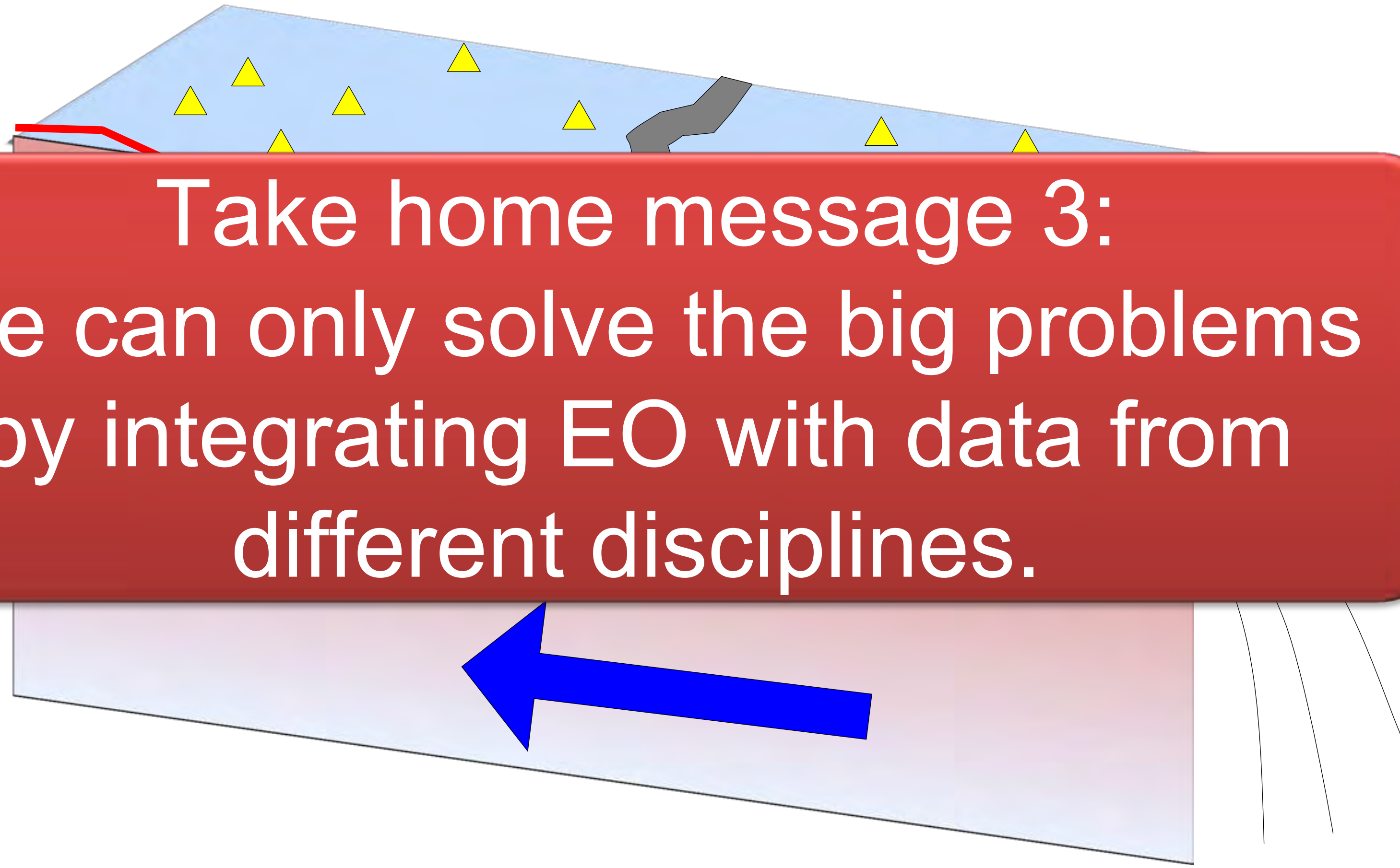




Take home message 3:
We can only solve the big problems by integrating EO with data from different disciplines.

Outline

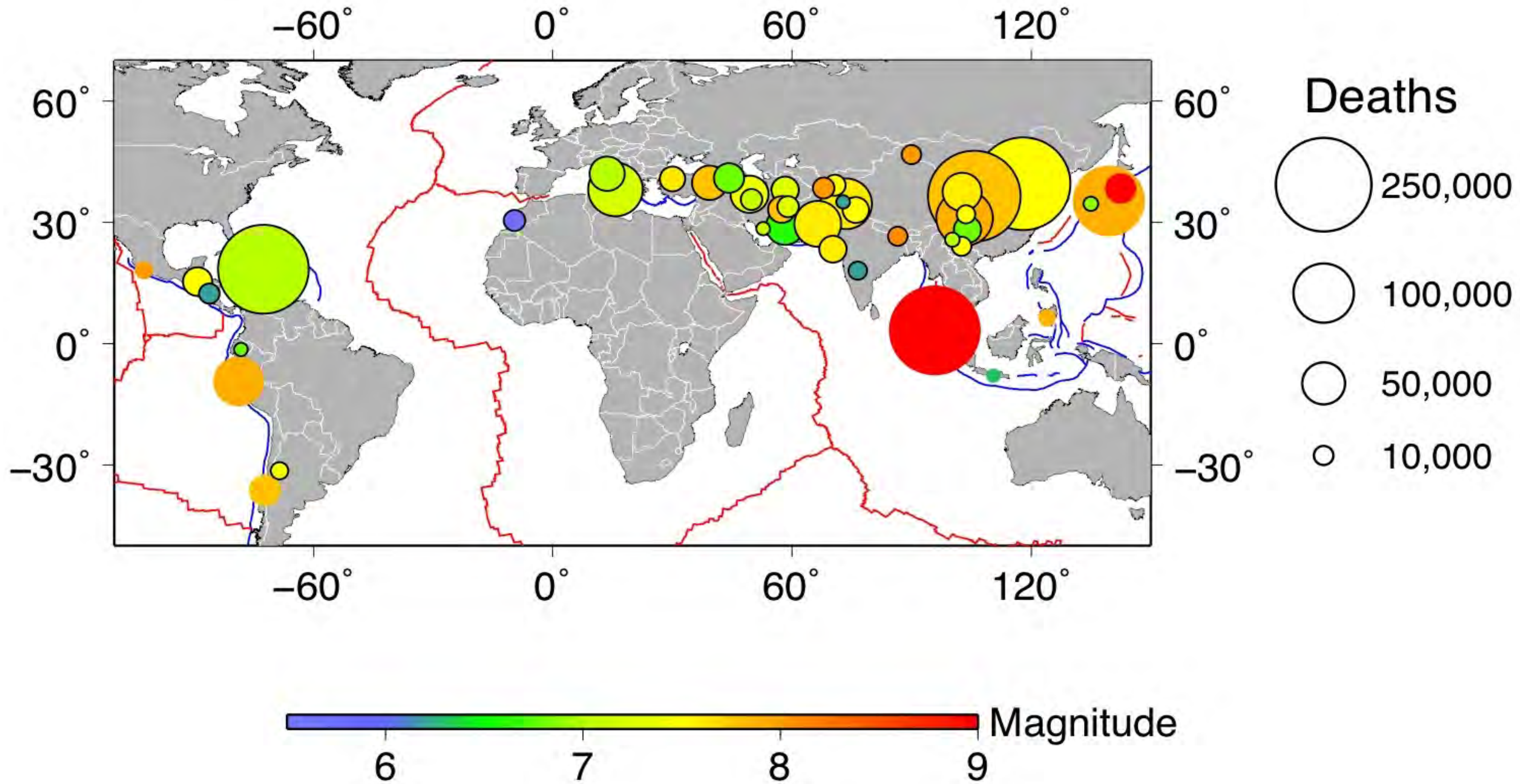
This Lecture: Using EO for tectonics

- Response
- Mitigation
- Science

Next Lecture: Using EO for volcanology

- Answering key questions in volcanology

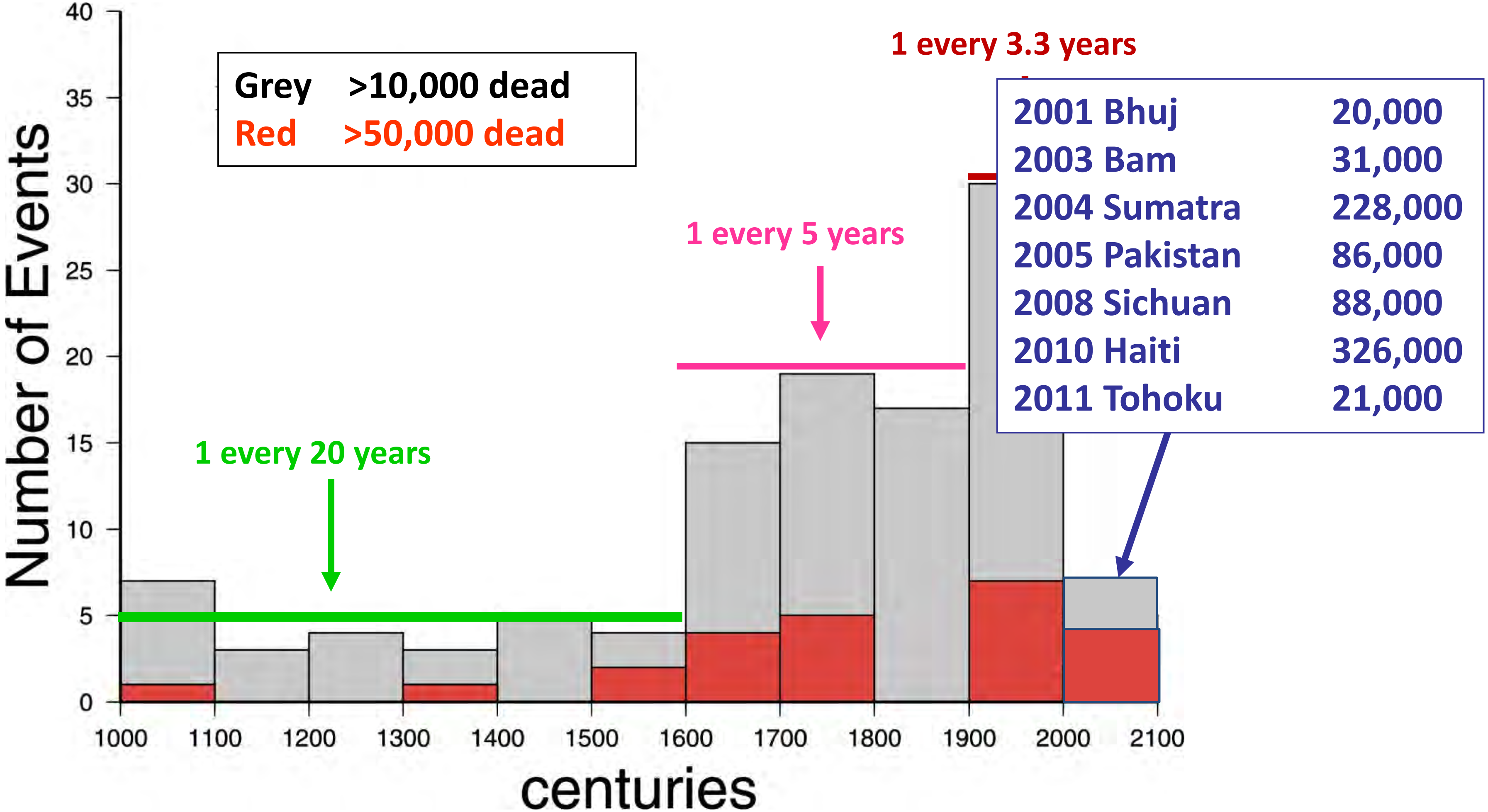
Using EO to understand tectonic processes



100 years of deadly earthquakes

Figure from http://comet.nerc.ac.uk/ earthquake workshop report

Earthquakes that killed more than 10,000 people



Slide courtesy James Jackson, Cambridge

31 December 2003, M6.6 Bam (Iran), 31,000 lives lost

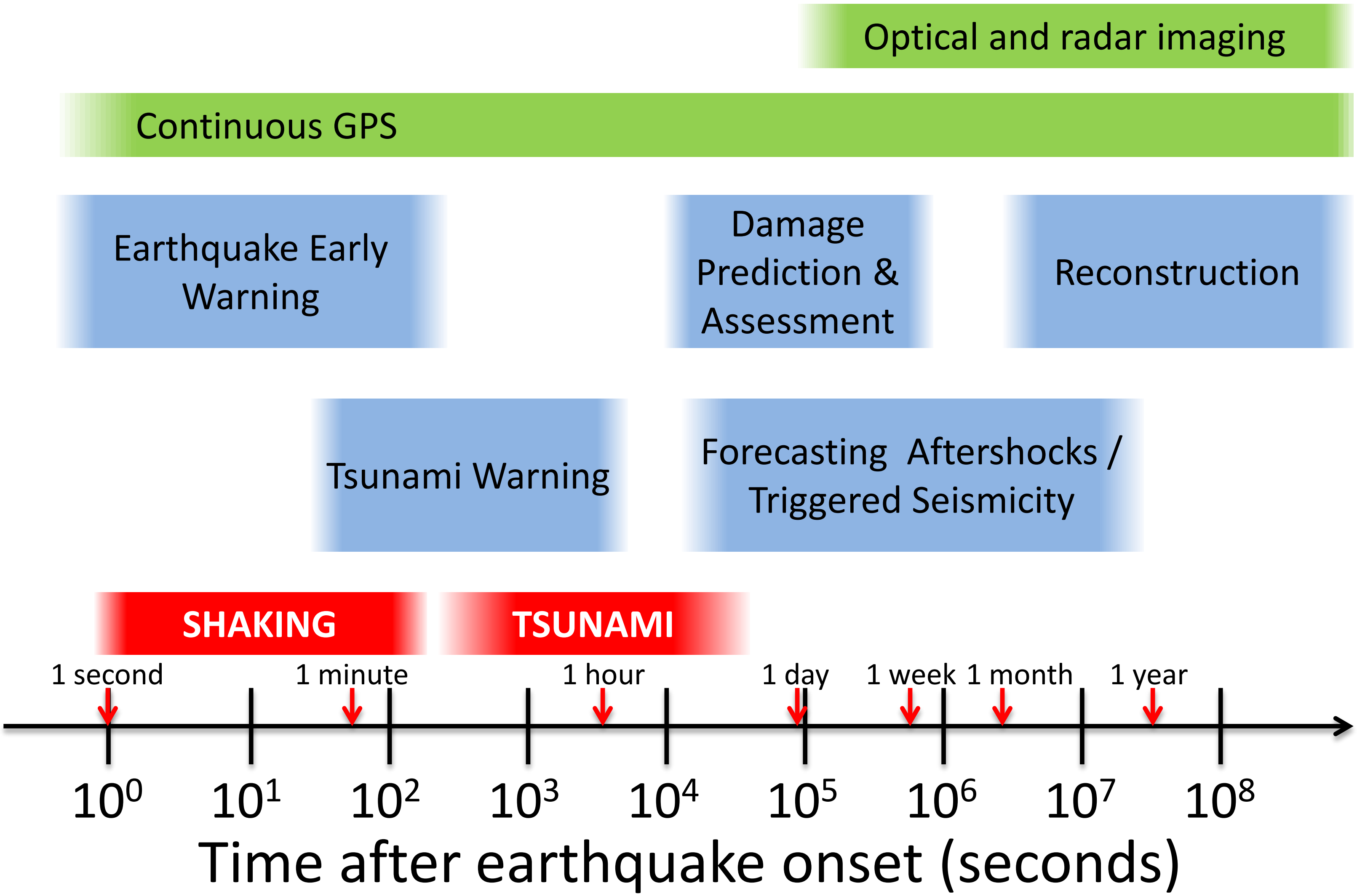
Reproduced with permission from England and Jackson, Nature Geoscience, 2011


10/7/2013
31 December 2003,
M6.6 Bam (Iran),
31,000 lives lost
Image © 2015 CNES / Astrium

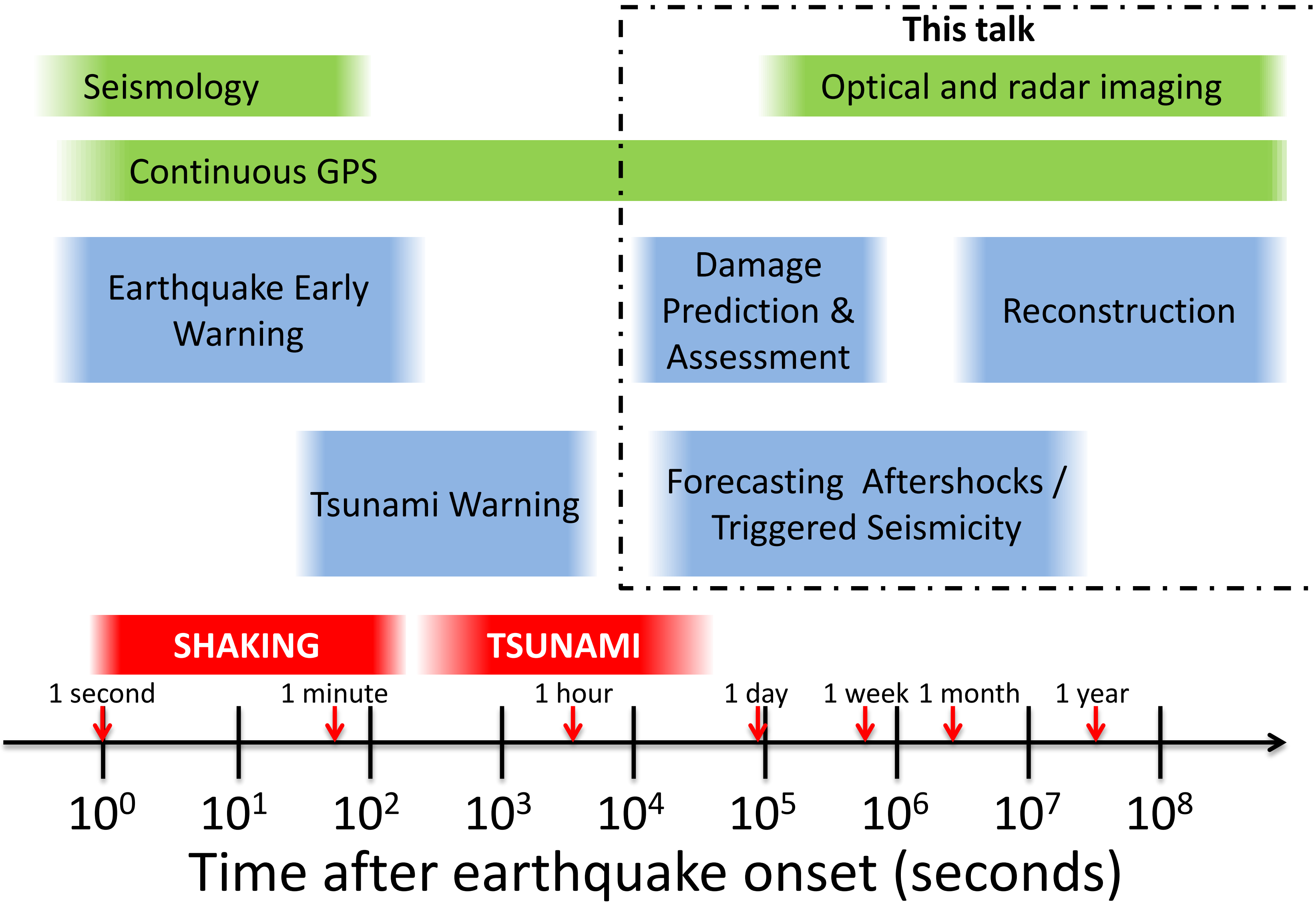
Photo: US Airforce


12 January 2010
M7.0 Haiti,
316,000 lives lost
UN Photo/Logan Abassi United Nations Development Programme

Timescales of response

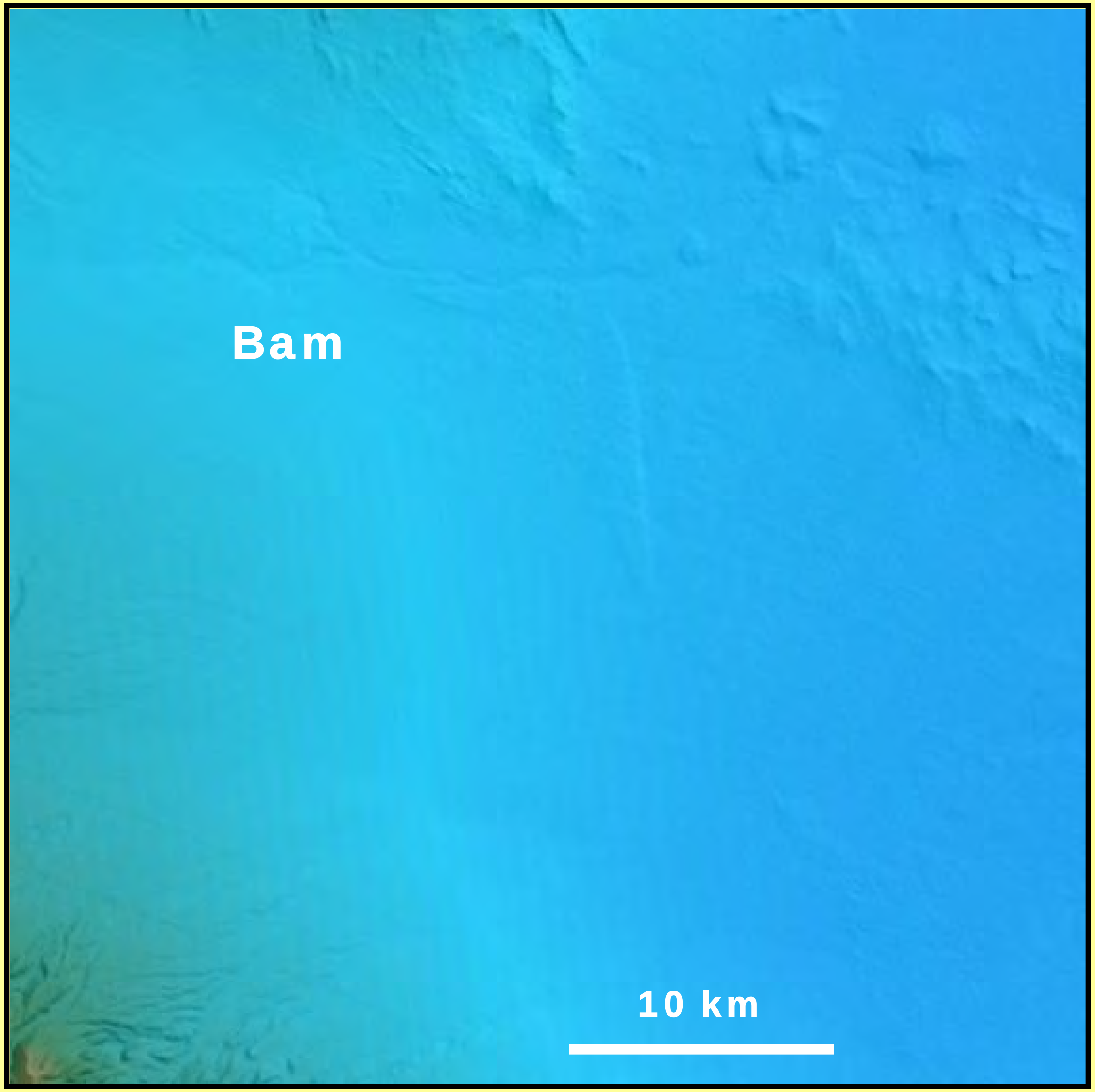


Timescales of response



The Bam earthquake – 26 December 2003

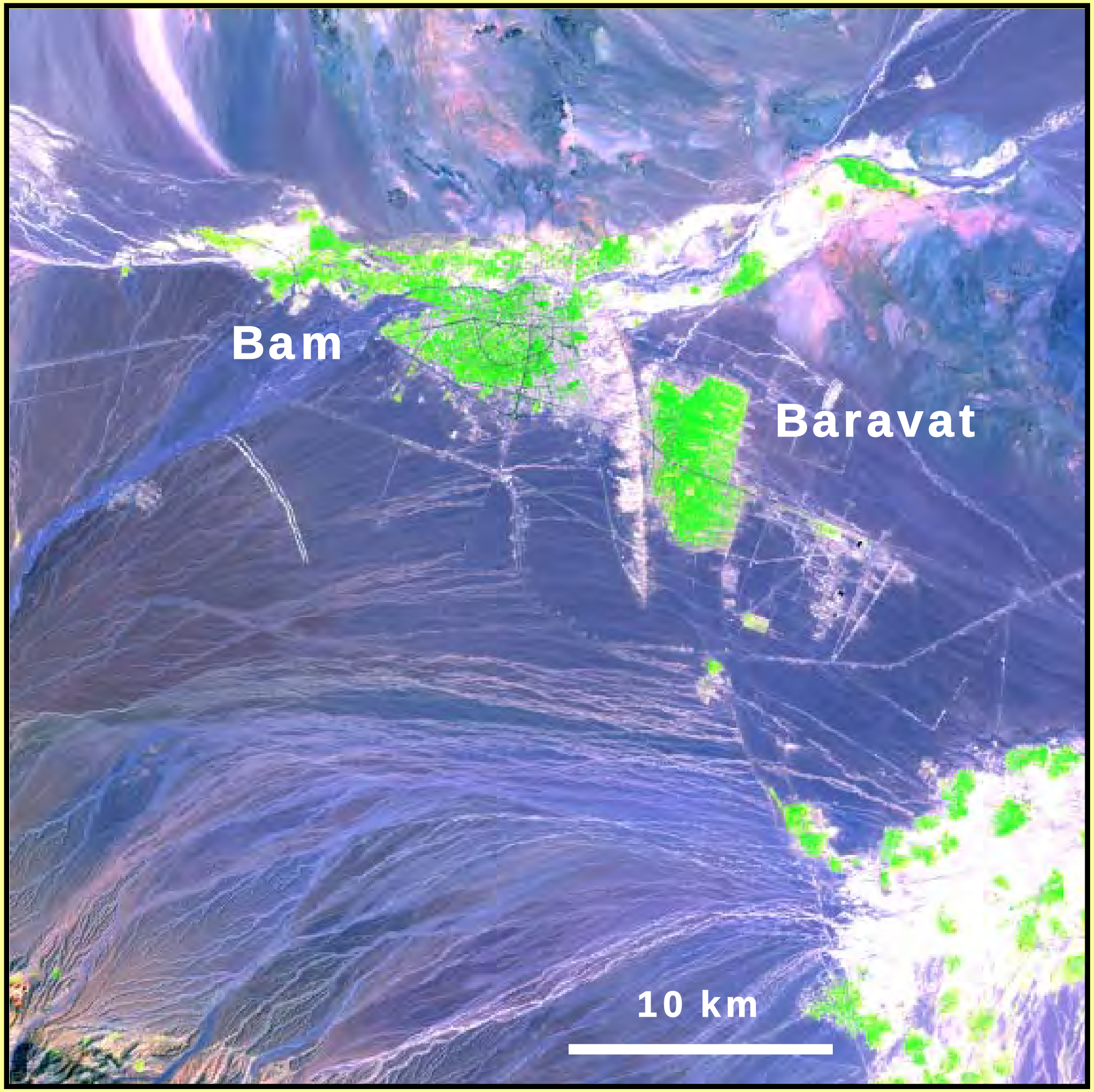
Main geomorphic features of the Bam area:



SRTM shaded relief topography

The Bam area

Main geomorphic features of the Bam area:

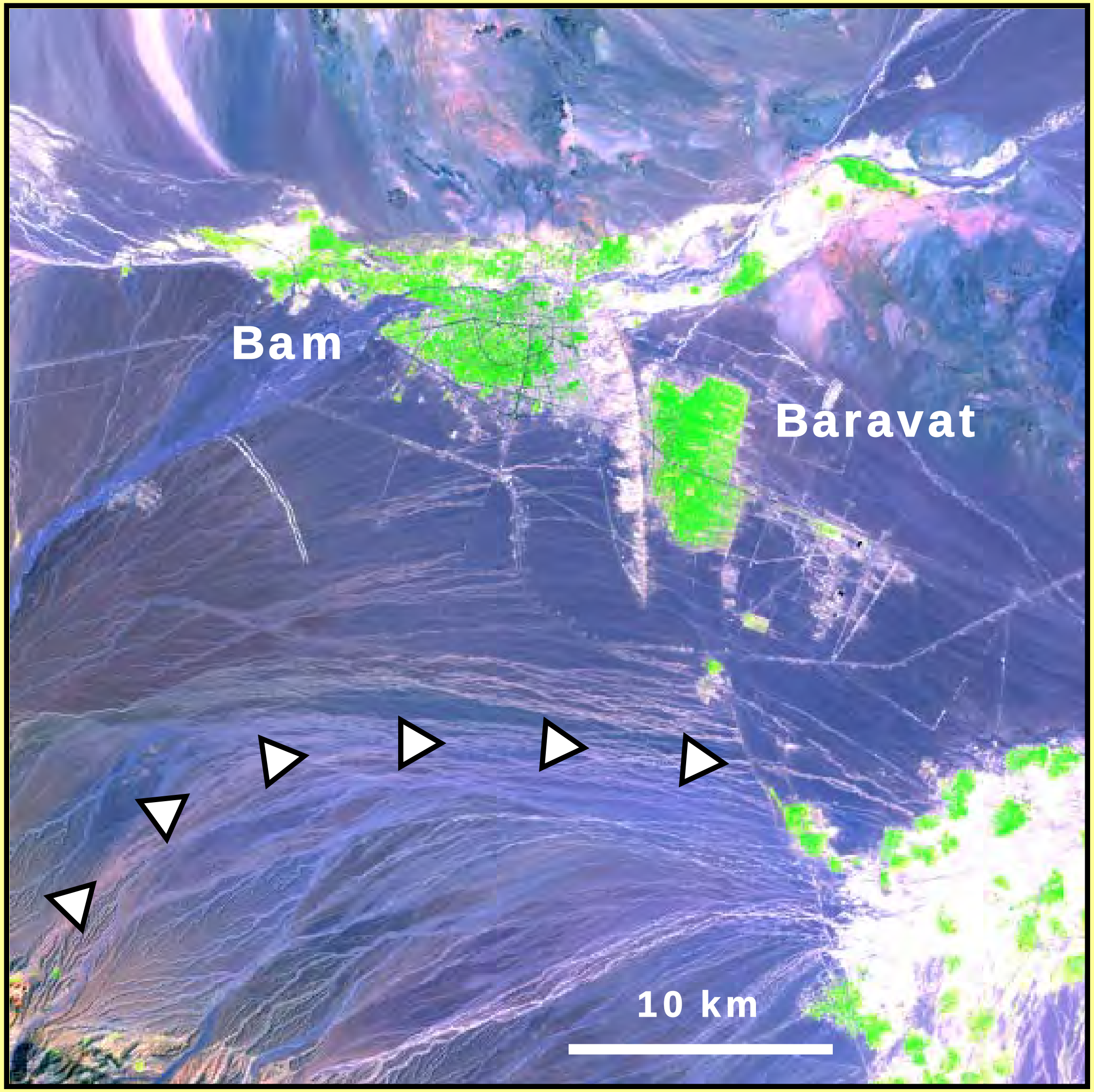


LANDSAT-7 ETM
541 false colour
green=vegetation

The Bam area

Main geomorphic features of the Bam area:

1: Alluvial fans from the Jebal Barez mountains to the SW

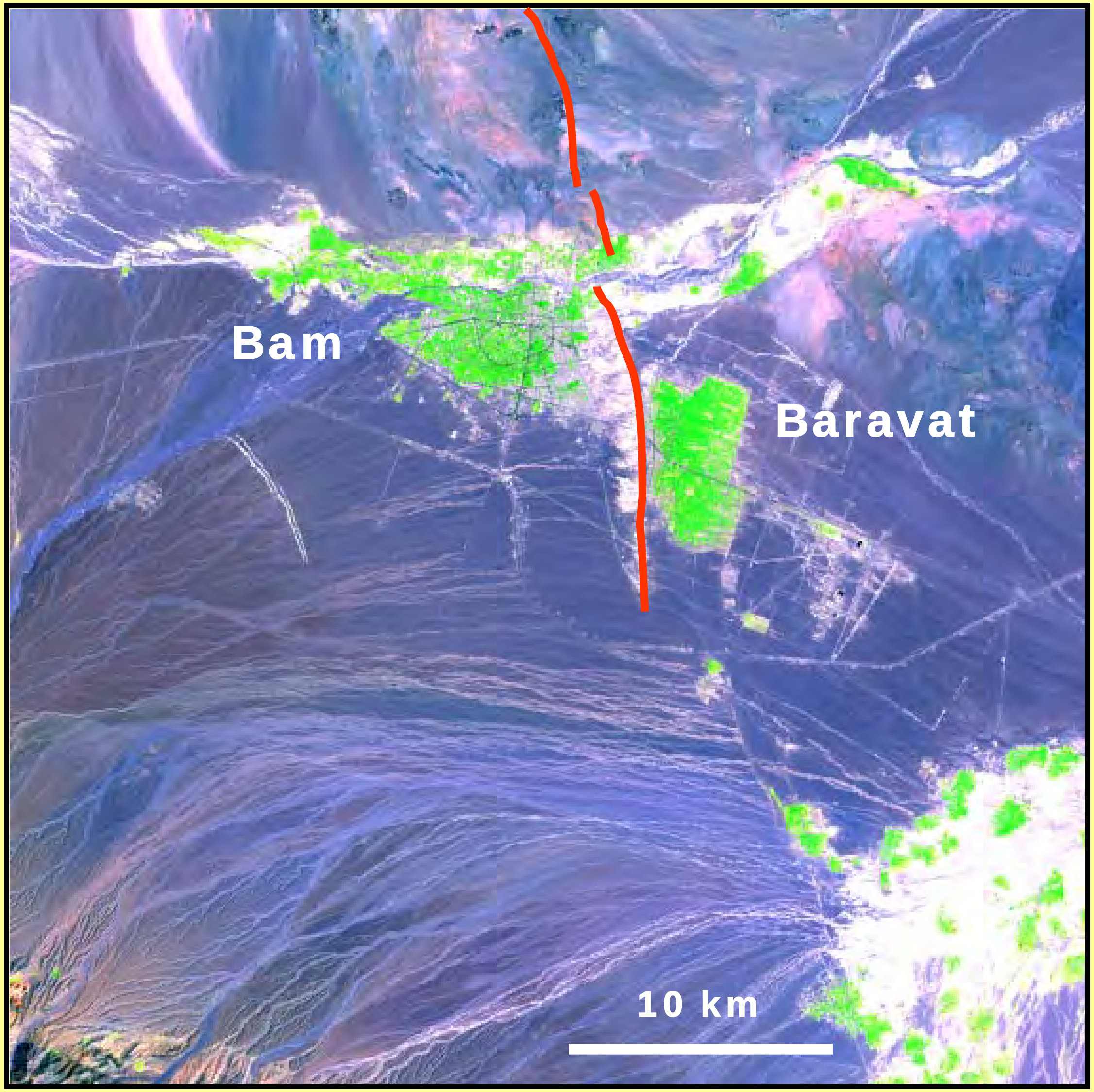


LANDSAT-7 ETM 541 false colour green=vegetation

The Bam area

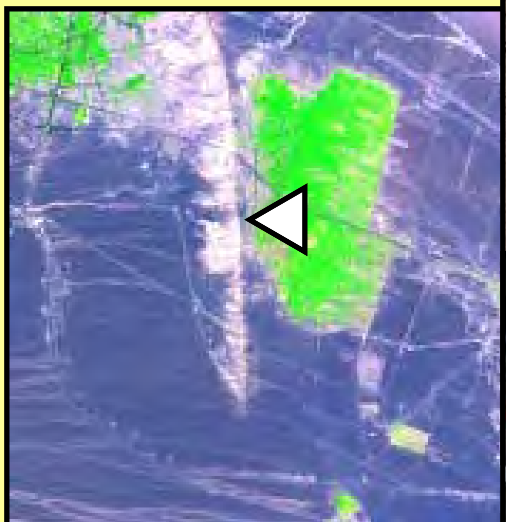
Main geomorphic features of the Bam area:

2: The Bam fault – a prominent ridge running between Bam and Baravat



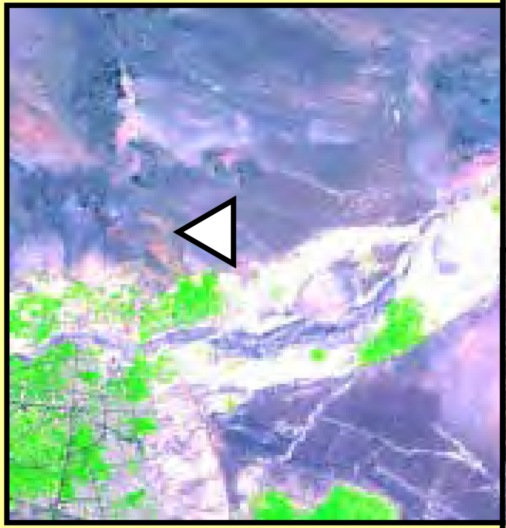
LANDSAT-7 ETM 541 false colour green=vegetation

The Bam fault



Post-earthquake field surveys found only minor cracking at the foot of the ridge...

The Bam fault



...and fault ruptures observed in the north were also minor (< 5 cm offset)

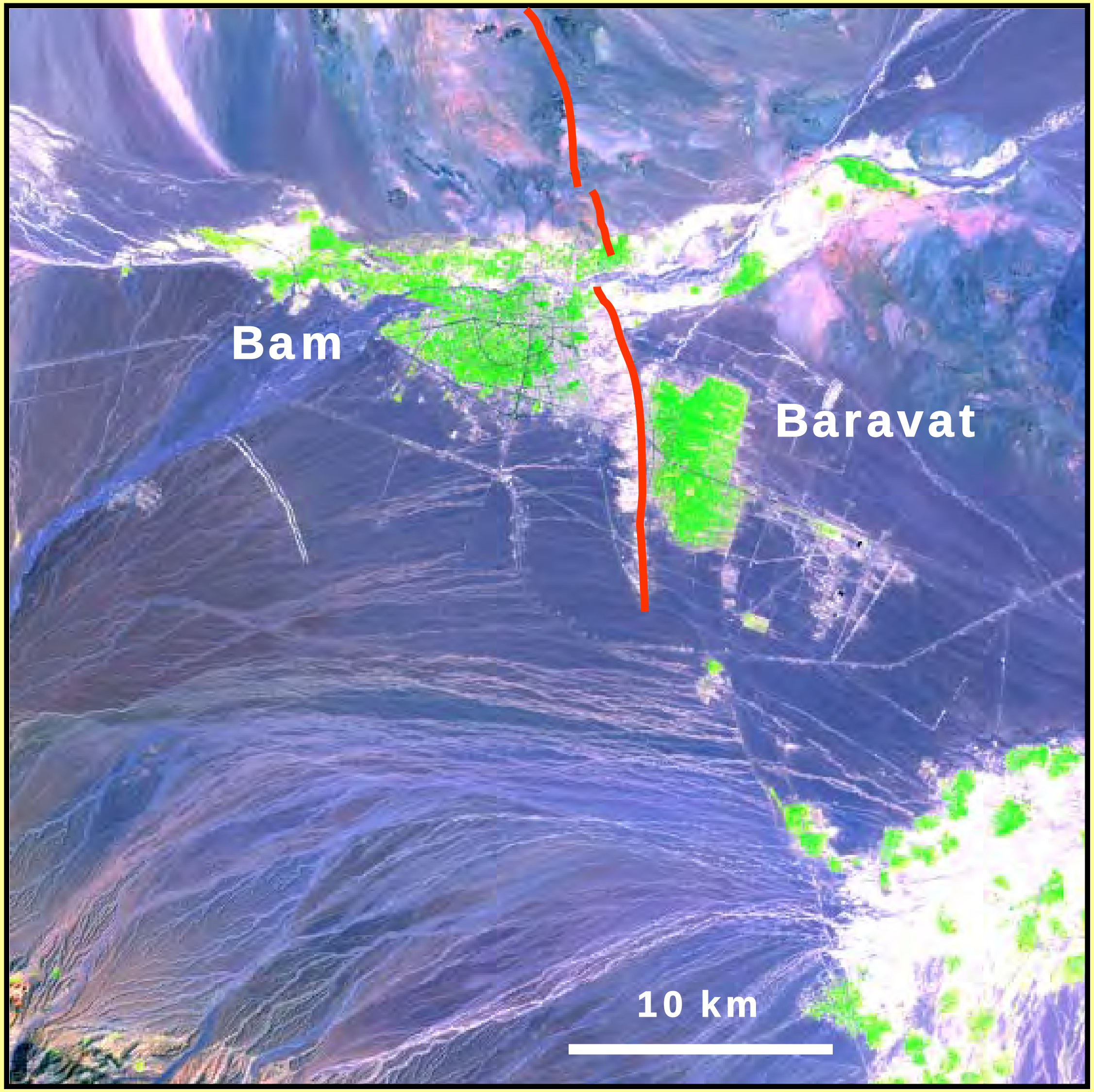
The Bam fault ?

BUT...

More damage in Bam than Baravat

Peak vertical acceleration of ~1g in central Bam

Very small surface rupture on Bam fault

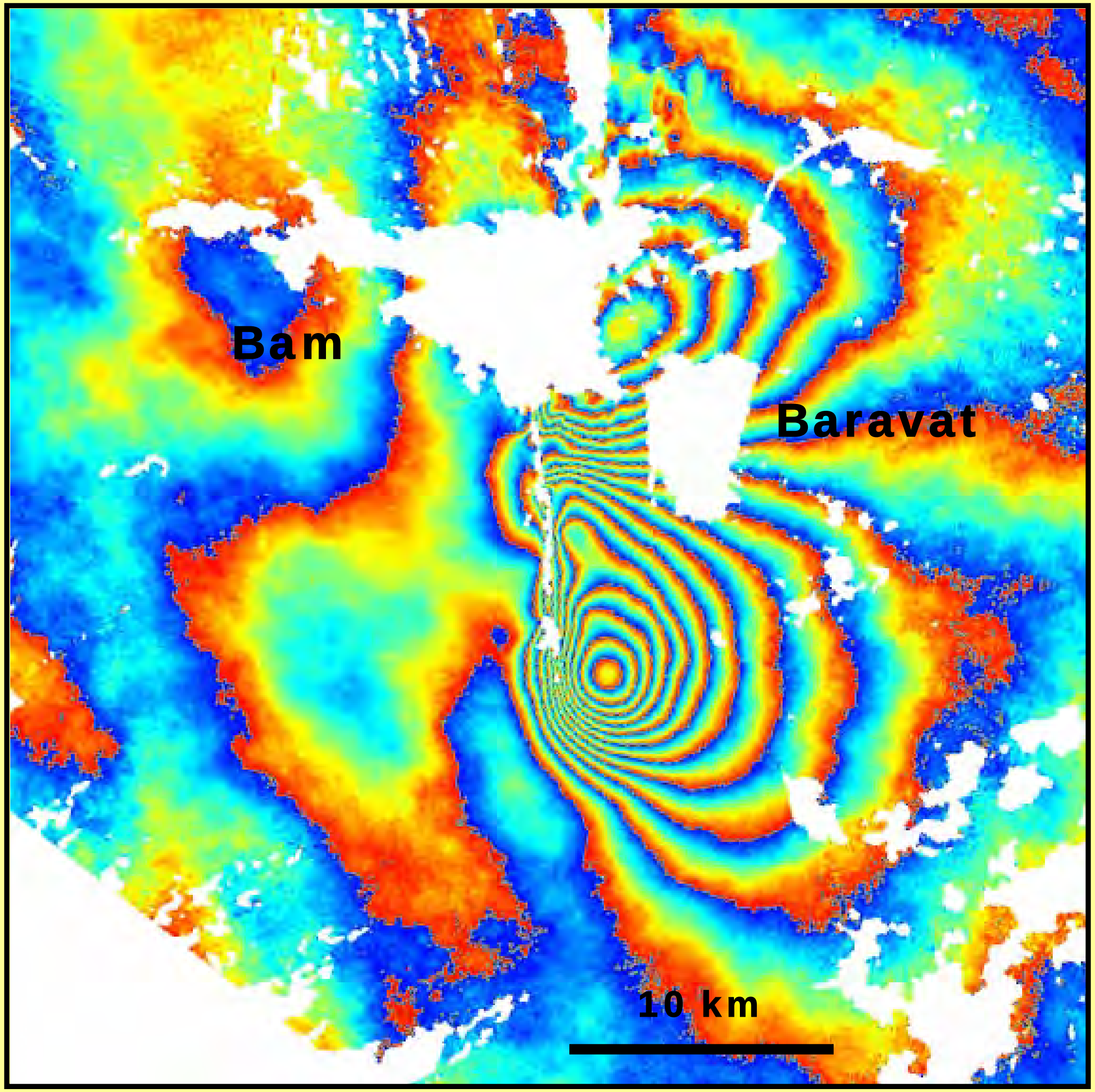


LANDSAT-7 ETM
541 false colour
green=vegetation

Preliminary InSAR data

First Bam interferogram (each colour cycle=2.8cm of deformation)

Constructed from Envisat ASAR data released for free by ESA

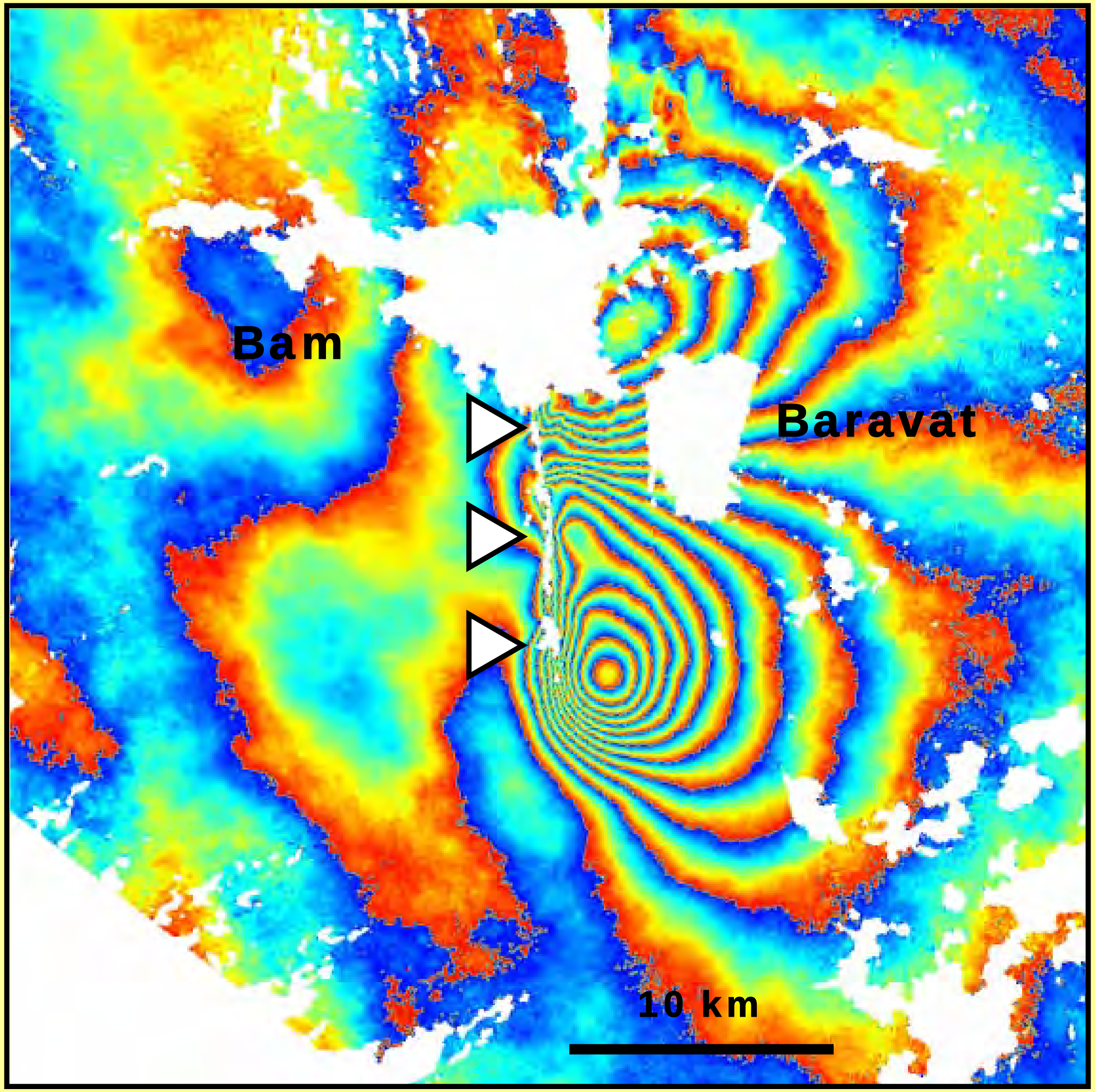


Preliminary InSAR data

There is a prominent band of incoherence running S of Bam

First Bam interferogram (each colour cycle=2.8cm of deformation)

Constructed from Envisat ASAR data released for free by ESA

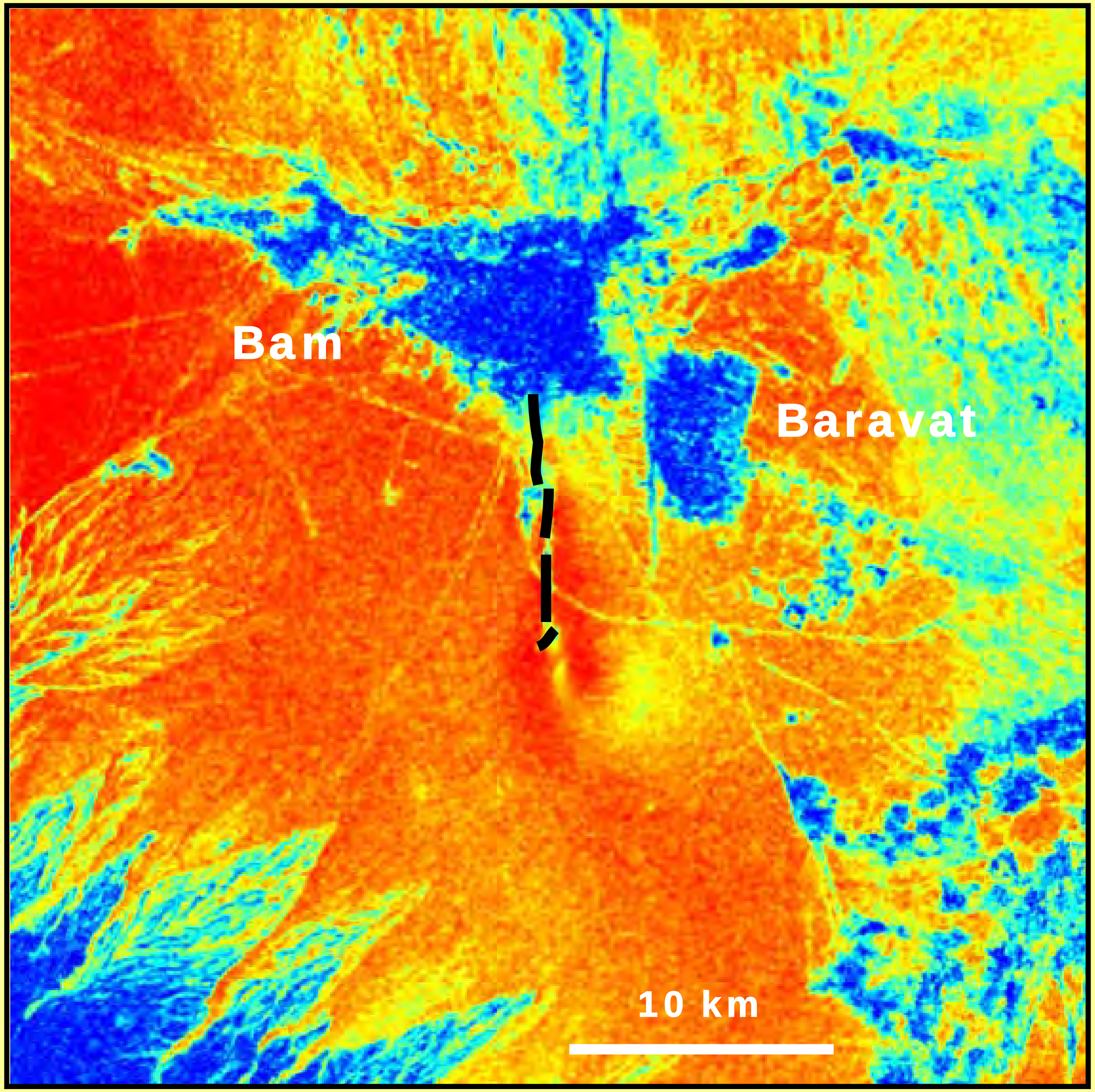


The Bam earthquake main fault

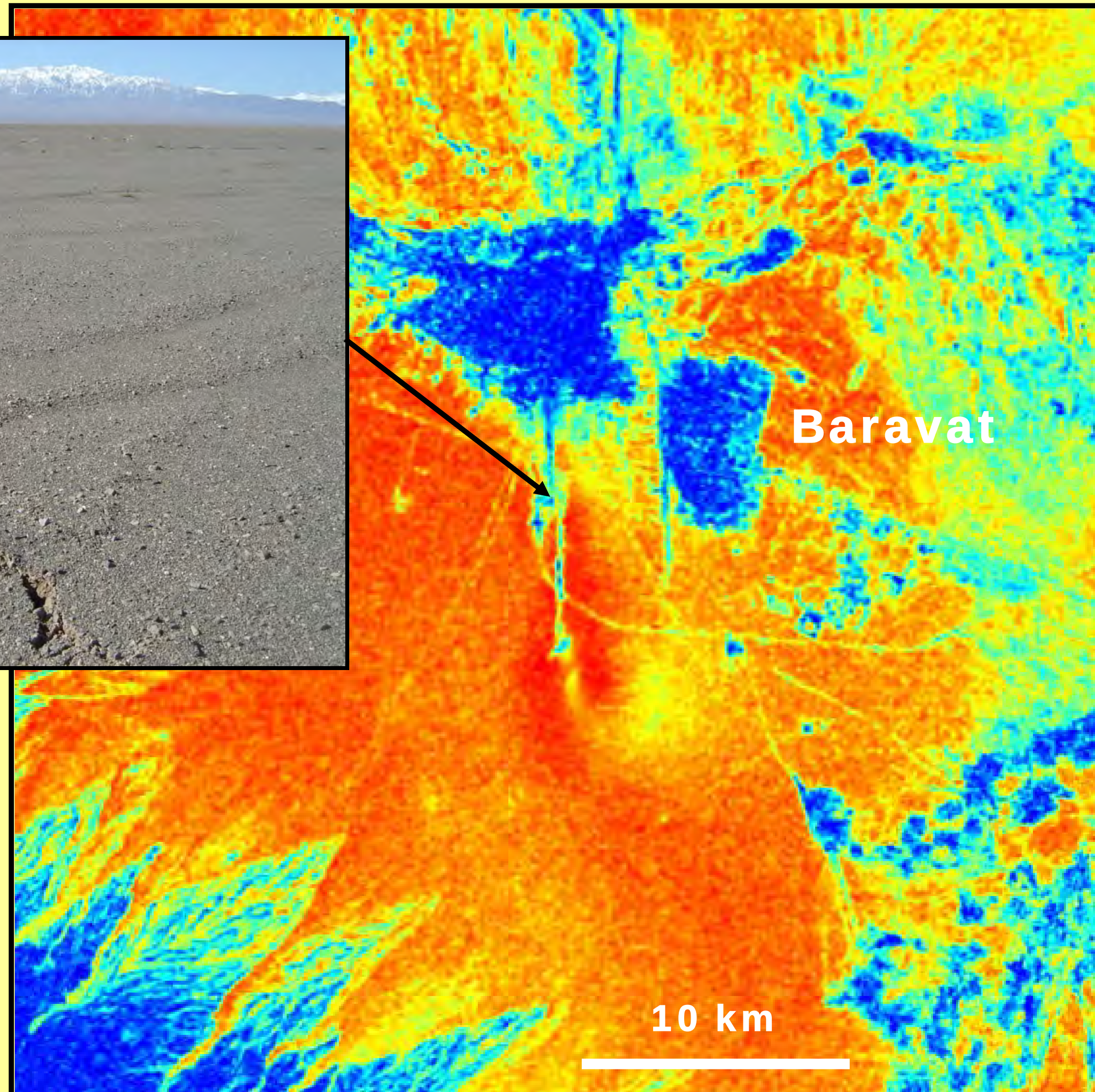
Low coherence indicates vegetation and surface damage

Interferometric coherence
Red = high
Blue = low

Constructed from Envisat ASAR data released for free by ESA

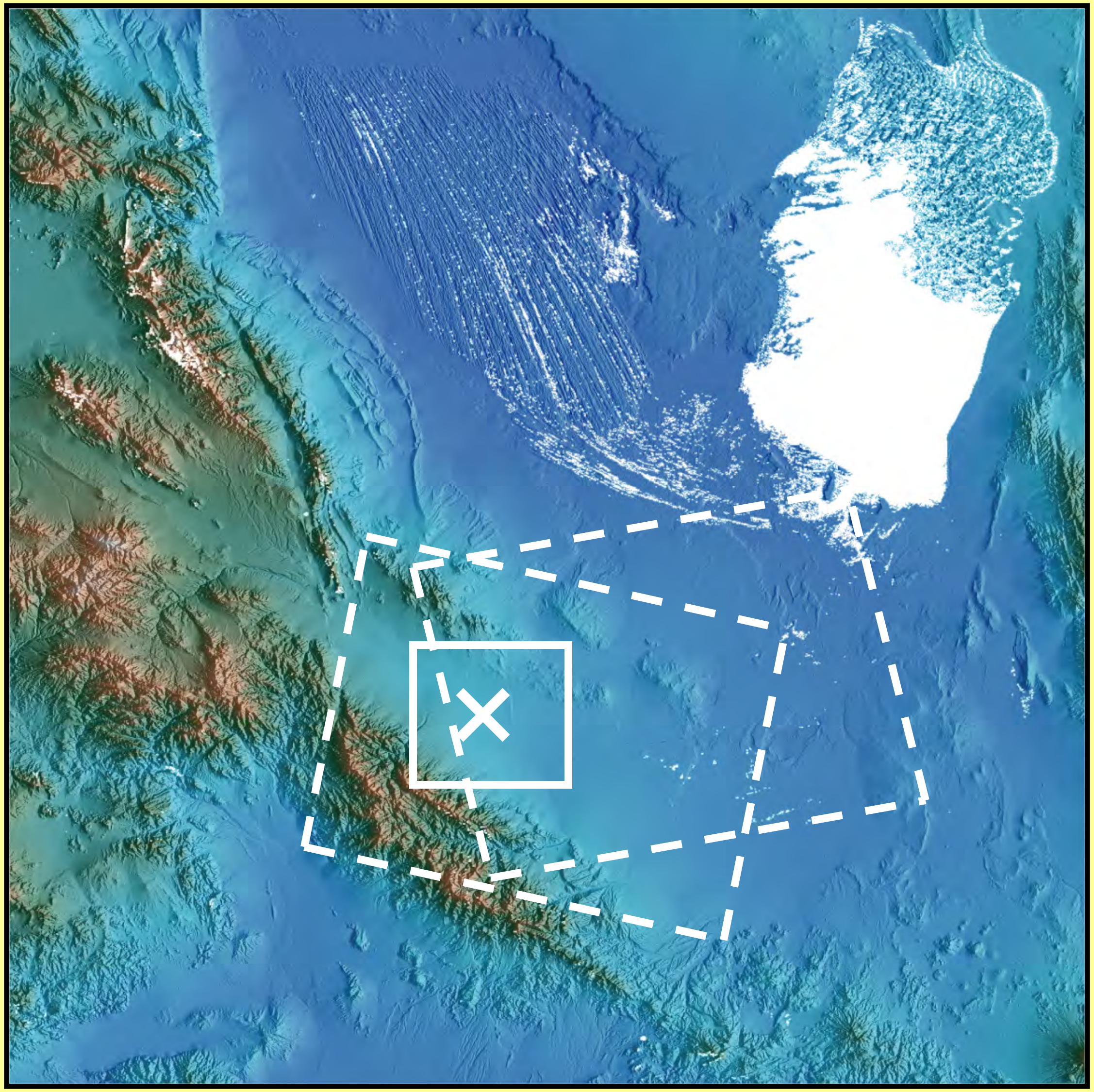


The Bam earthquake main fault



Surface rupture found in the field – right-lateral offsets of ~20 cm

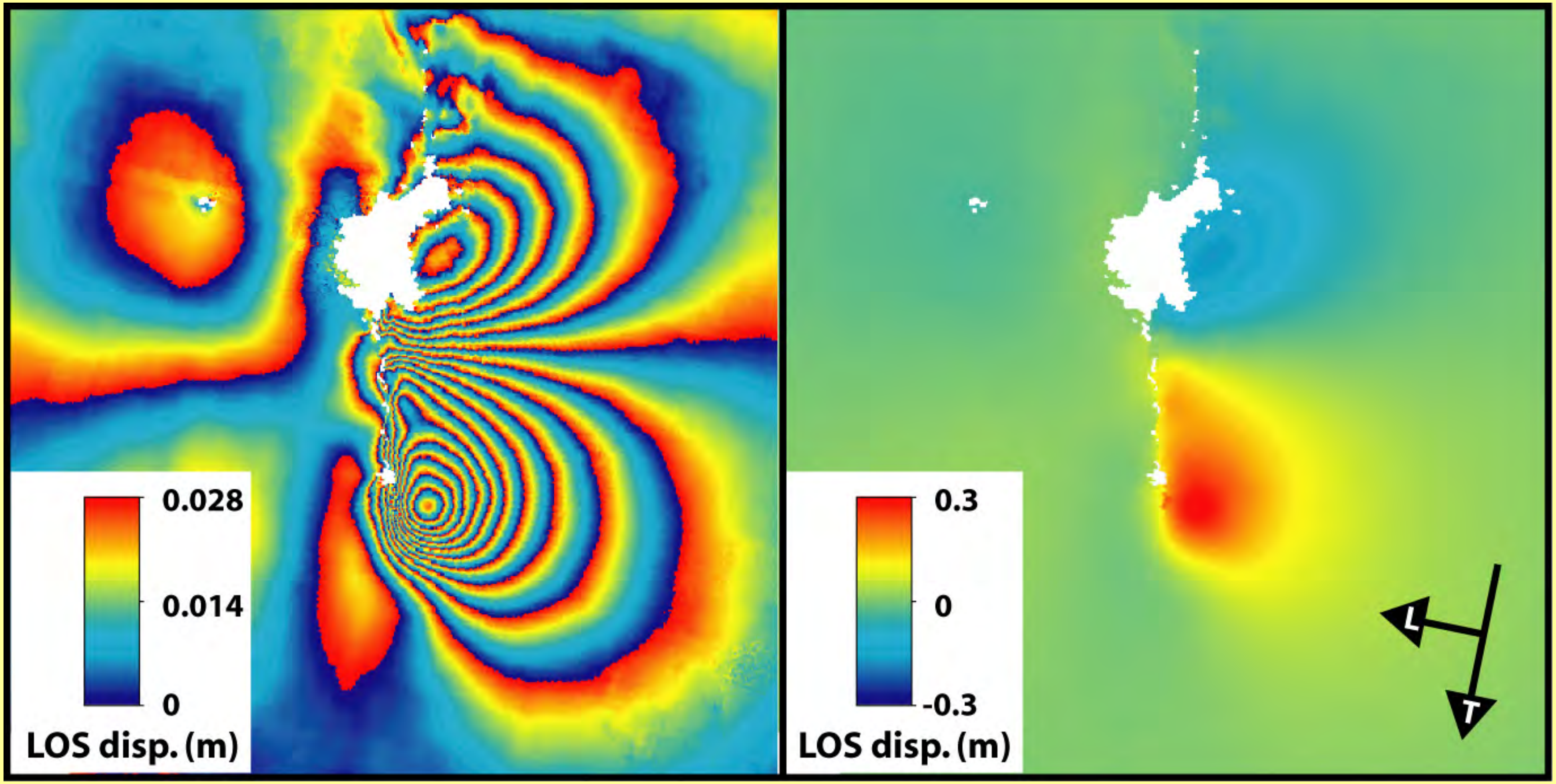
ASAR data for the Bam earthquake



SRTM shaded-relief topography

Descending track interferogram

Track 120, beam mode I2, 03/12/2003 – 07/02/2004

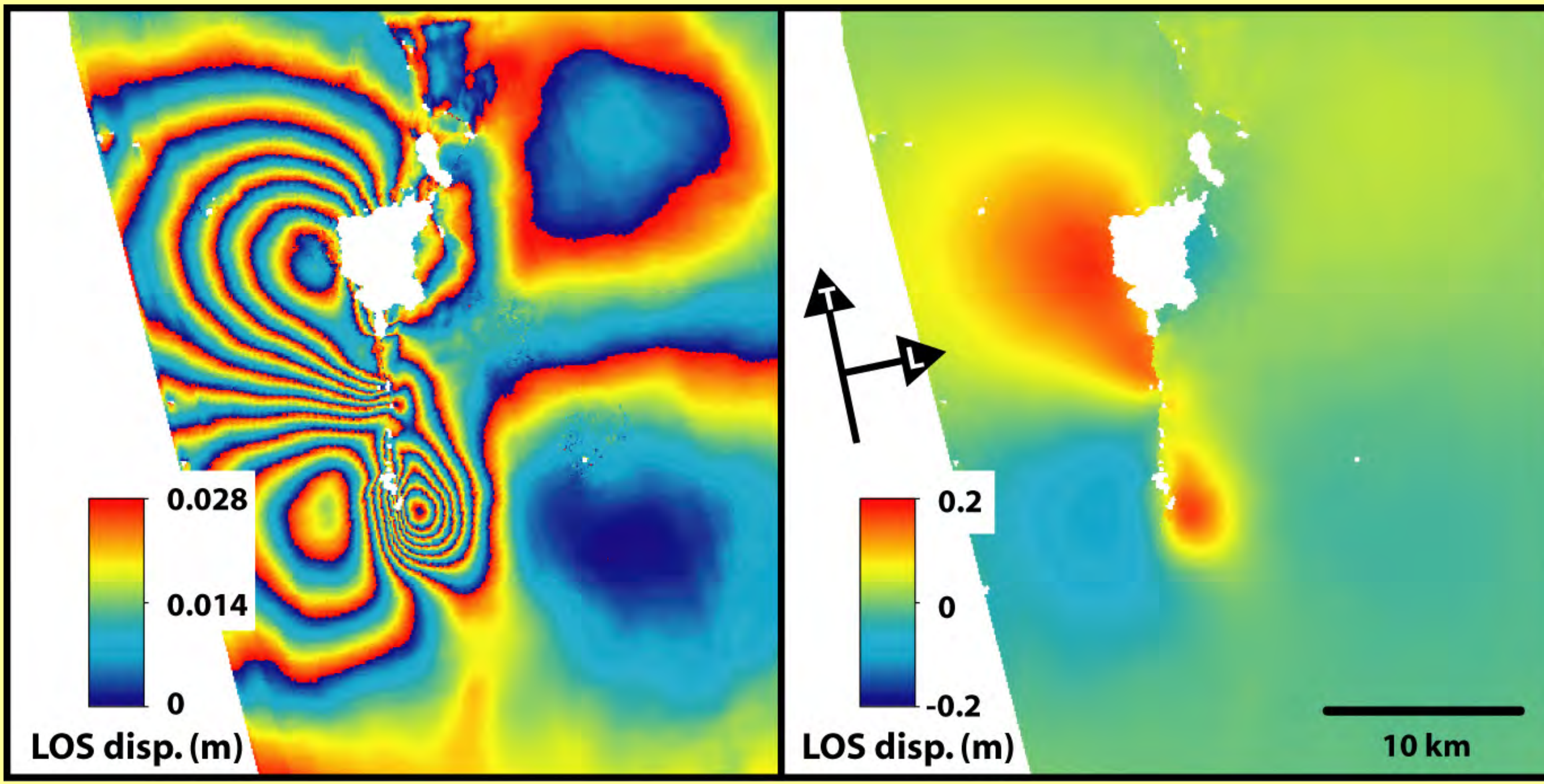


Wrapped

Unwrapped

Ascending track interferogram

Track 385, beam mode I2, 16/11/2003 – 25/01/2004



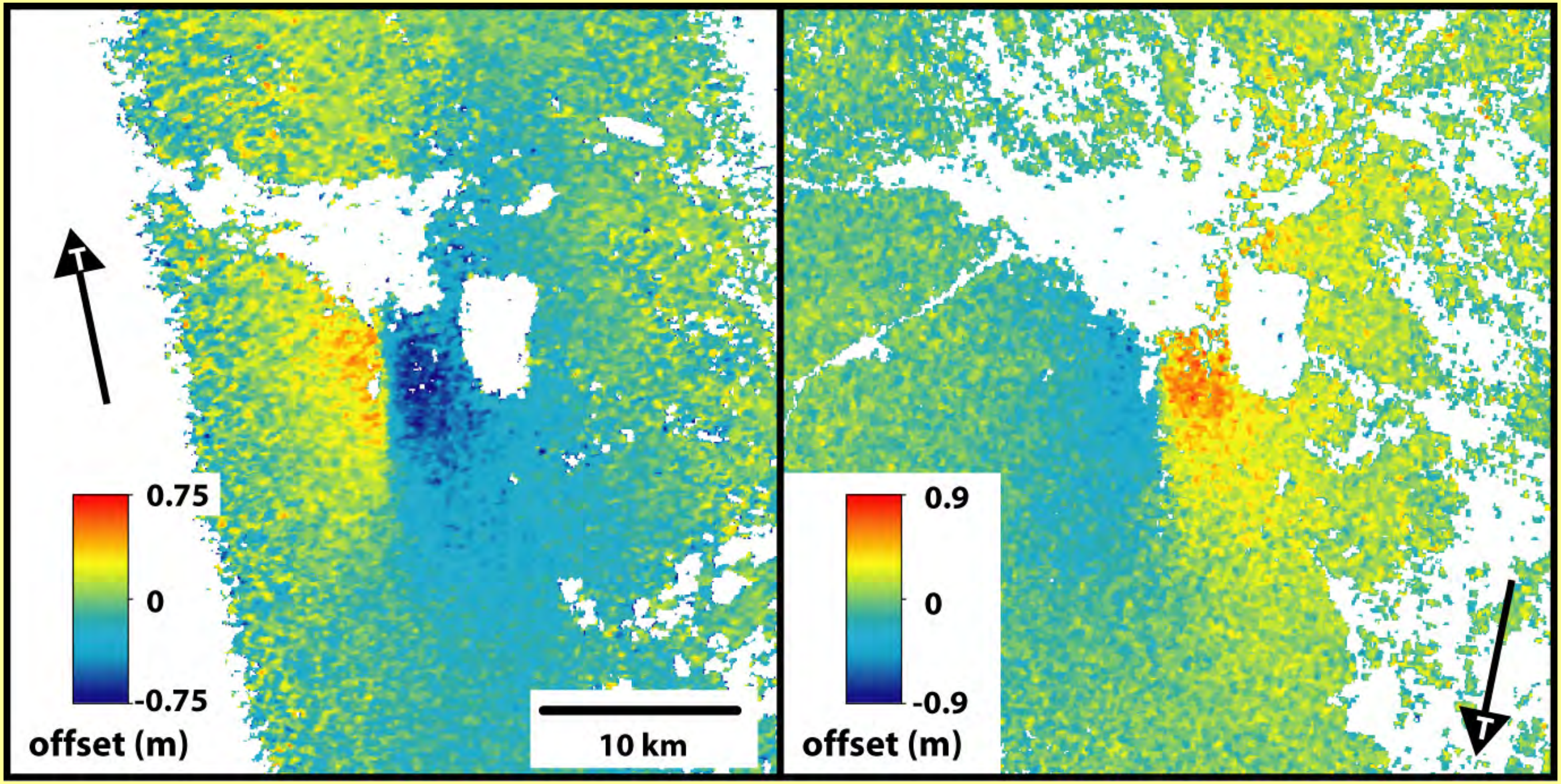
Wrapped

Unwrapped

Azimuth offsets

Ascending

Descending



Determining 3D displacements

If the 3D displacement at a pixel is given by

u = $[u_x, u_y, u_z]$, then...

Ascending interferogram, $d_1 = \mathbf{los_A} \cdot \mathbf{u}$

Descending interferogram, $d_2 = \mathbf{los_D} \cdot \mathbf{u}$

Ascending az. offsets, $d_3 = \mathbf{los_{AO}} \cdot \mathbf{u}$

Descending az. offsets, $d_4 = \mathbf{los_{DO}} \cdot \mathbf{u}$

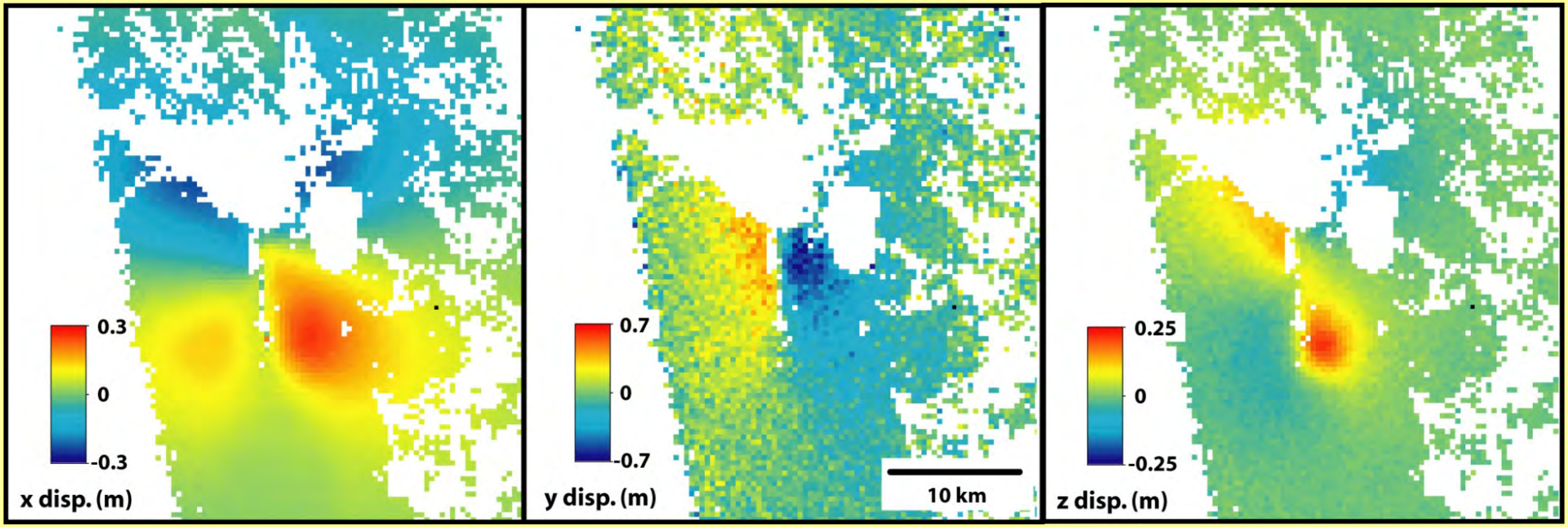
Which can be rewritten as a matrix equation,

$\mathbf{d} = \mathbf{Lu}$, and solved for **u**.

See e.g. Wright, T.J, B. Parsons, Z. Lu., Geophys Res. Lett. 30(18), p.1974, 2003

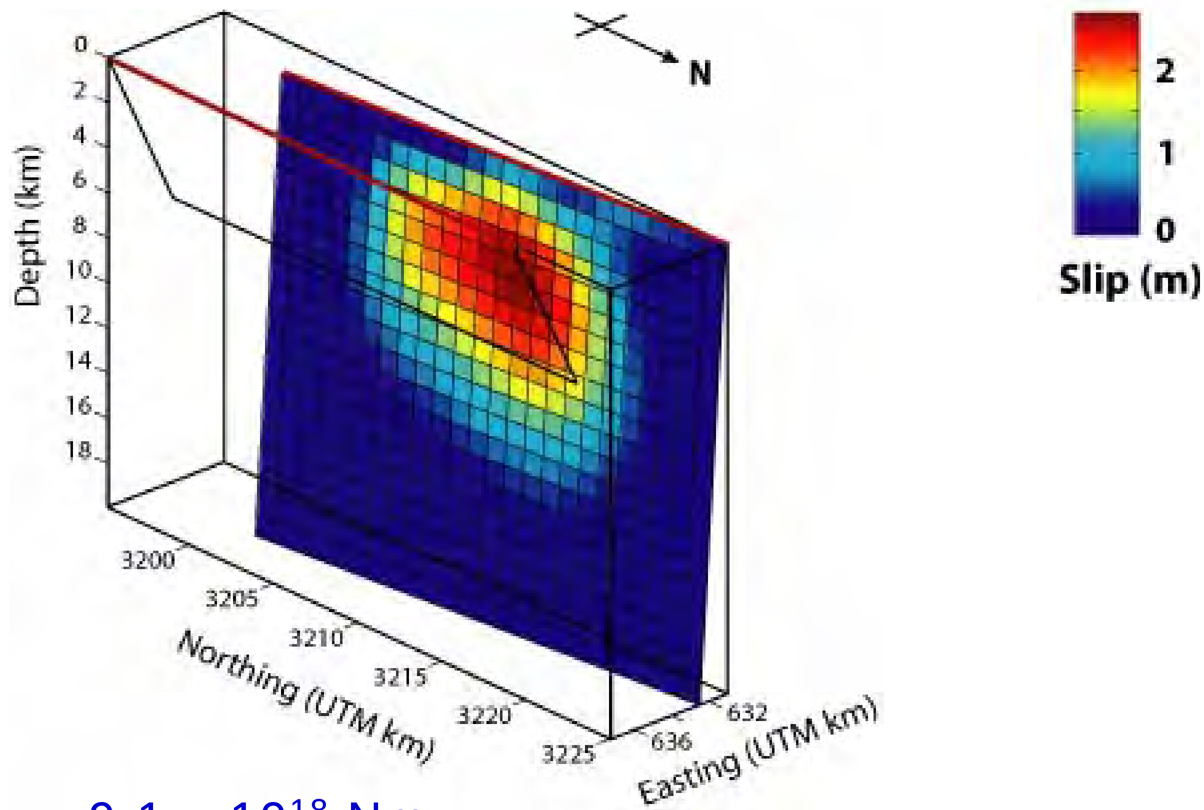
Bam earthquake 3D displacements

East North Up



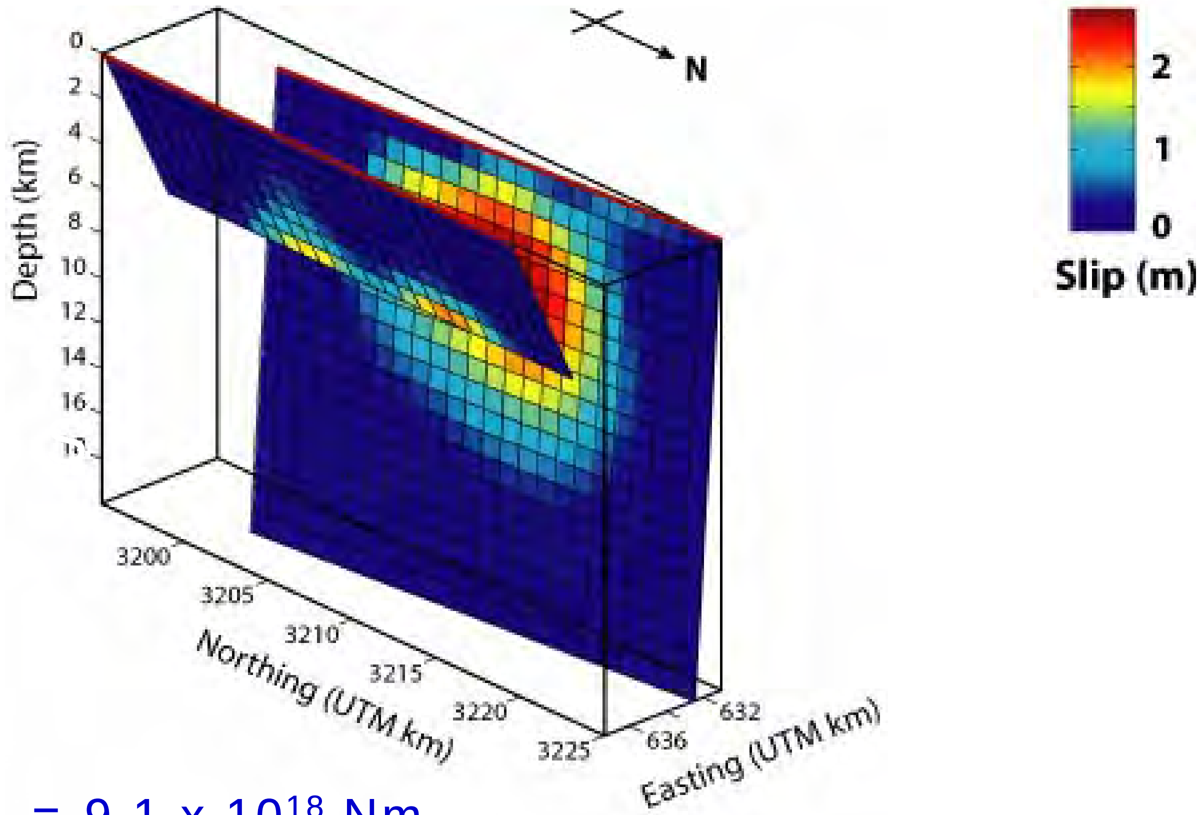
σ = 0.01 m σ = 0.09 m σ = 0.01 m

Variable slip model



Main fault, $M_0 = 9.1 \times 10^{18}$ Nm

Variable slip model



Main fault, M_0 = 9.1 x 10^{18} Nm

Secondary fault, M_0 = 1.6 x 10^{18} Nm

On 25 April 2015, a large earthquake of Mw 7.8 struck in central Nepal. This video shows the motion of a GPS station versus people's reactions in Kathmandu. You see the arrival of the earthquake and then the back and forth motion as the seismic waves slosh back and forth across the basin of sediments that underlie the city.

Initial location and magnitude comes rapidly from seismology…

earthquake.usgs.gov/earthquakes/eventpage/us20002926#general_summary

General

- **Summary**
- Interactive Map
- Google Earth KML

Impact

- Summary
- Did You Feel It?
- Tell Us!
- Shakemap
- PAGER

Scientific

- Summary
- Origin
- Moment Tensor
- Finite Fault
- Waveforms

Latest Earthquakes

M7.8 - 34km ESE of Lamjung, Nepal

IX DYFI? | **IX** ShakeMap | **RED** PAGER

Location

Data Source US[2]

28.147°N 84.708°E depth=15.0 km (9.3 mi)

View interactive map

Time

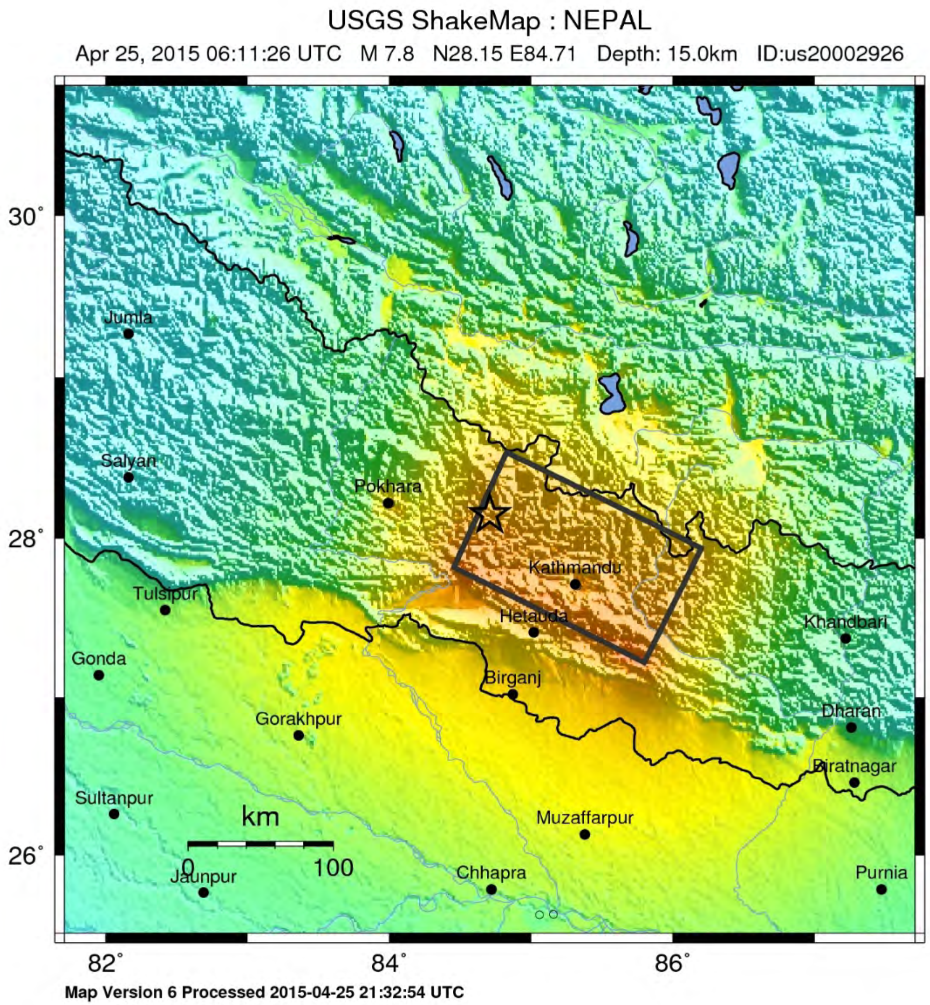
2015-04-25 06:11:26 (UTC)
2015-04-25 08:11:26 (UTC+02:00) in your timezone
Times in other timezones

Nearby Cities

34km (21mi) ESE of Lamjung, Nepal
58km (36mi) NNE of Bharatpur, Nepal
73km (45mi) E of Pokhara, Nepal
76km (47mi) NW of Kirtipur, Nepal
77km (48mi) NW of Kathmandu, Nepal

Initial location and magnitude comes rapidly from seismology…

v1 EQ + 19 minutes
v2 EQ + 52 minutes
v3 EQ + 83 minutes
v4 EQ + 2 hours
v5 EQ + 4 hours
v6 EQ + 15 hours



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

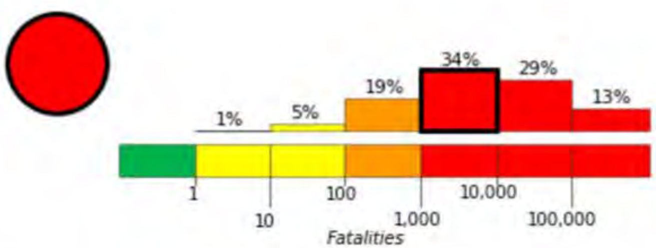
Thanks to Richard Briggs, Gavin Hayes, Bill Barnhard, USGS

M7.8 - 36km E of Khudi, Nepal

USGS PAGER Alert

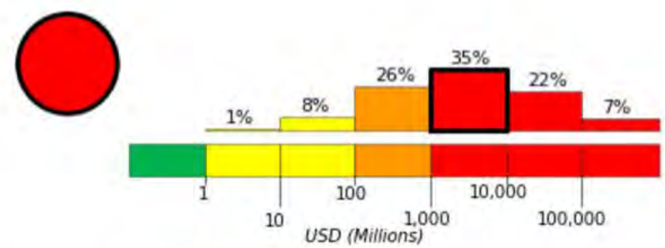
2015-04-25 06:11:25 UTC | 28.231°N 84.731°E | 8.2 km depth

Estimated Fatalities



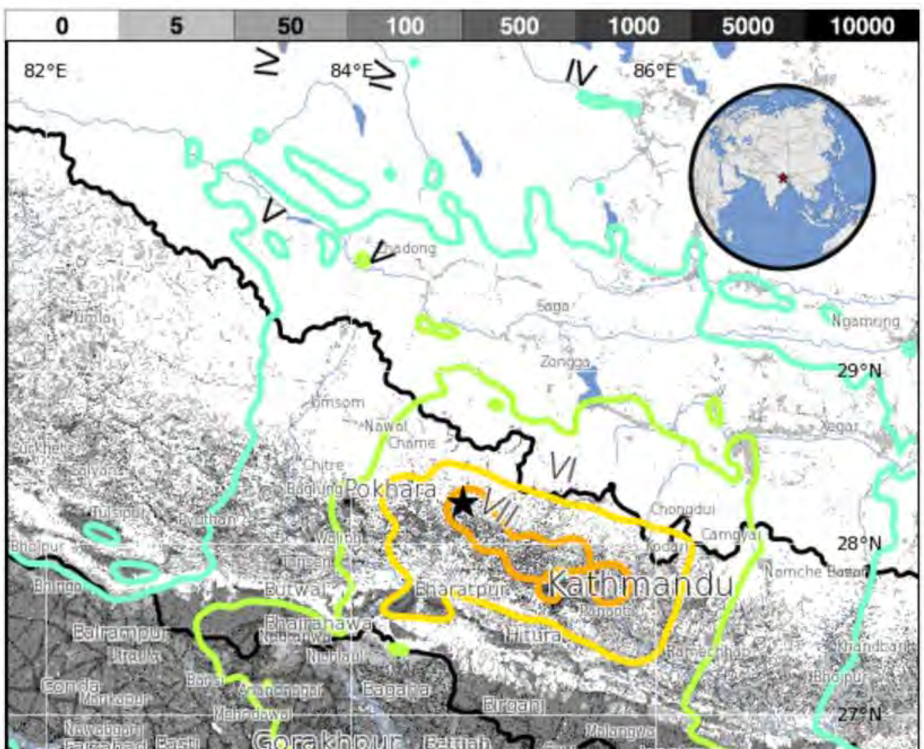
Red alert for shaking-related fatalities and economic losses. High casualties and extensive damage are probable and the disaster is likely widespread. Past red alerts have required a national or international response.

Estimated Economic Losses



Estimated economic losses are 8-40% GDP of Nepal.

Estimated Population Exposure to Earthquake Shaking



Structure Information Summary

Overall, the population in this region resides in structures that are highly vulnerable to earthquake shaking, though some resistant structures exist. The predominant vulnerable building types are unreinforced brick masonry and rubble/field stone masonry construction.

Secondary Effects

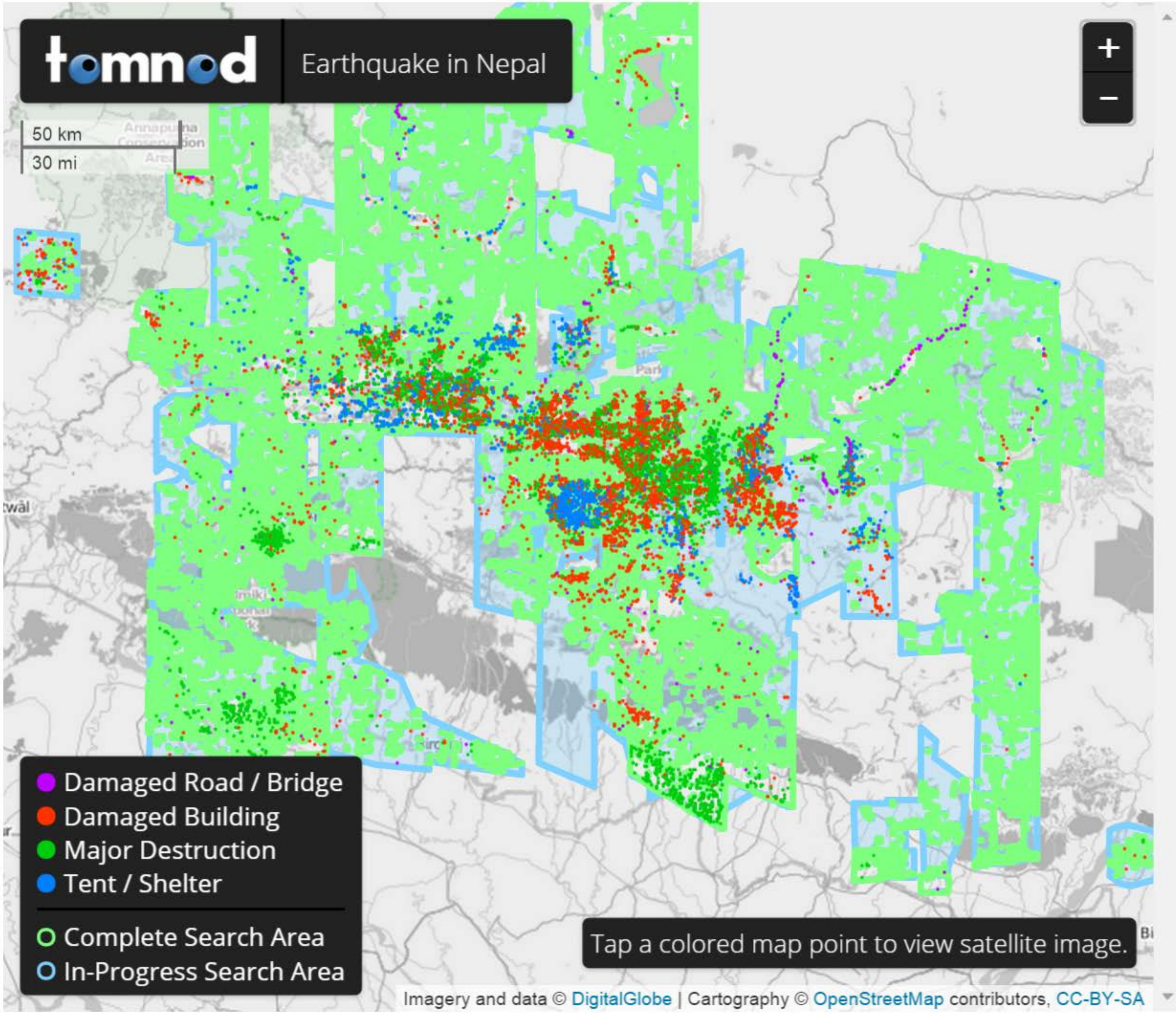
Recent earthquakes in this area have caused secondary hazards such as landslides and liquefaction that might have contributed to losses.

Selected Cities Exposed

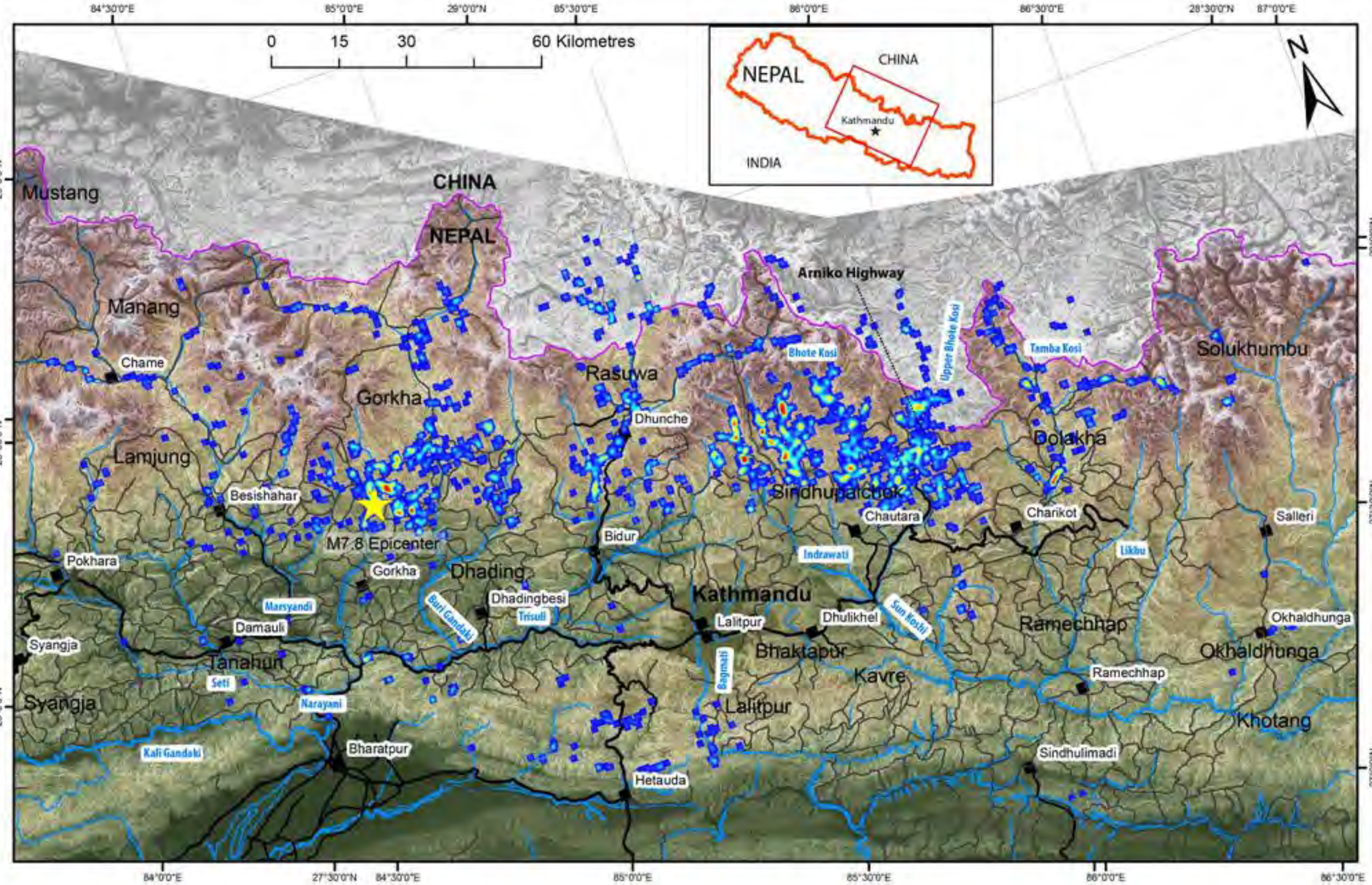
MMI	City	Pop.
VIII	Kathmandu	1,442 k
VIII	Patan	183 k
VIII	Kirtipur	45 k

International Charter Space & Major Disasters

Charte Internationale Espace et Catastrophes Majeures



tomnod
Earthquake in Nepal
50 km
30 mi
Damaged Road / Bridge
Damaged Building
Major Destruction
Tent / Shelter
Complete Search Area
In-Progress Search Area
Tap a colored map point to view satellite image.
Imagery and data © DigitalGlobe | Cartography © OpenStreetMap contributors, CC-BY-SA



25 April 2015 Nepal Earthquake

Mapped Landslide Intensity

(revision 3.0 - 21 May 2015)

Description of mapped landslide features: This map has been compiled from optical satellite imagery across the area that experienced shaking during the 25 April Gorkha earthquake, available up to 21 May 2015. Approx. 3600 landslides have been identified and mapped as polylines marking the landslide location and length from head to toe. All landslides shown are either new landslides triggered by the earthquake, or those which have been reactivated by the earthquake. The main colour map shows landslide distribution. The purpose of this inventory and map is to describe the overall spatial distribution of landsliding triggered by the earthquake, and not for site-specific assessment. The map is intended to provide an overview of landsliding. Image quality is low in steep terrain meaning precise landslide locations may be inaccurate by up to 100 m. Key rivers, valleys and roads are labelled, and the yellow star indicates epicentre of 25 April 2015 M7.8 earthquake. Note that this inventory does not include failures which occurred following the 12 May 2015 earthquake.
Landslide data available: https://data.hdx.rwlabs.org/group/nepal-earthquake.

Map Key:
Overview of the affected area. All areas in the map extent have been assessed using at least pan-sharpened LandSat 8 imagery (15 m) and re-examined using high-resolution (< 3 m) optical imagery, which now also covers the majority of the affected area.

Legend:
High / Low — Relative landslide intensity, showing number of mapped landslides / km^2.
Colour scale: Blue - *c.* 1 landslide / km^2, Red - *c.* 29 landslides / km^2.

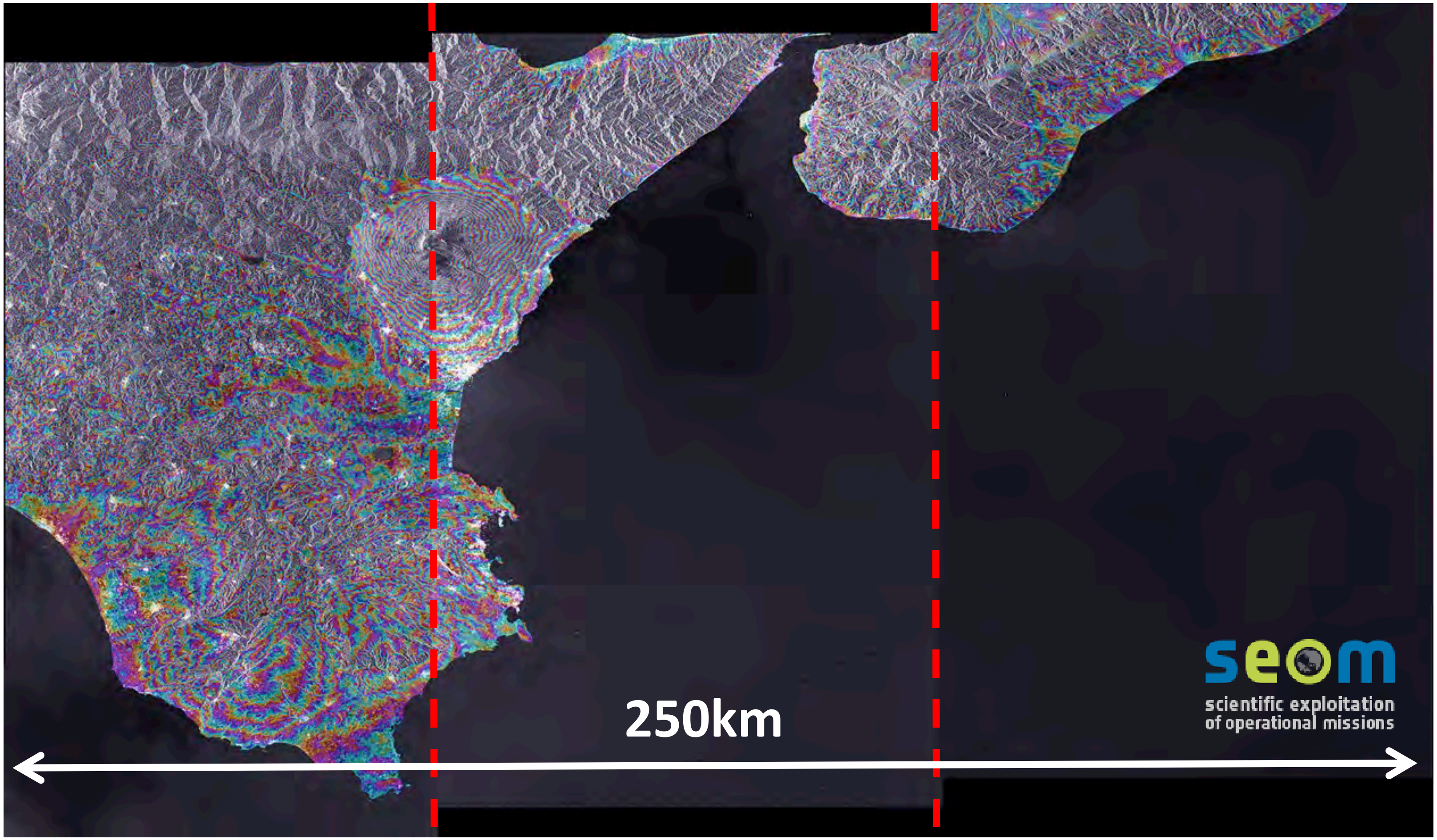
Map information:
- Satellite data have been provided via the International Charter Space and Major Disasters and freely available online viewers: WorldView @ Digital Globe; USGS LandSat8; Bhuvan RS2; Astrium Imagery; Google Crisis. Vector data: OSM. Digital Elevation Model: ASTER.
- Geolocation of landslides may not be accurate. No liability concerning the content or use thereof is assumed by the producer.

Contributors: Durham University, www.dur.ac.uk/geography; Earthquakes without Frontiers, www.ewf.nerc.ac.uk; British Geological Survey, www.bgs.ac.uk.

Sentinel-1 Constellation Facts

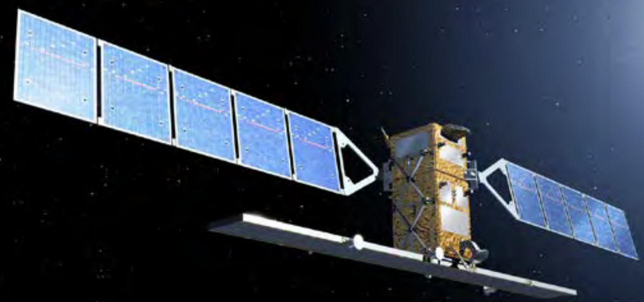
- 1A launched 3 April 2014
- 1B launched 22 April 2016
- 1st EU "Copernicus" satellite
- C-band radar, 12 day repeat
- Duty cycle, up to 25 mins/orbit
- 20 year operational mission

The Sentinel-1 standard mode is "Interferometric Wide Swath": IWS/TOPS (Terrain Observation with Progressive Scans)



Copernicus data (2014)/ESA/DLR Microwave and Radar Institute–SEOM Insarap study

Why is Sentinel-1 a game changer?

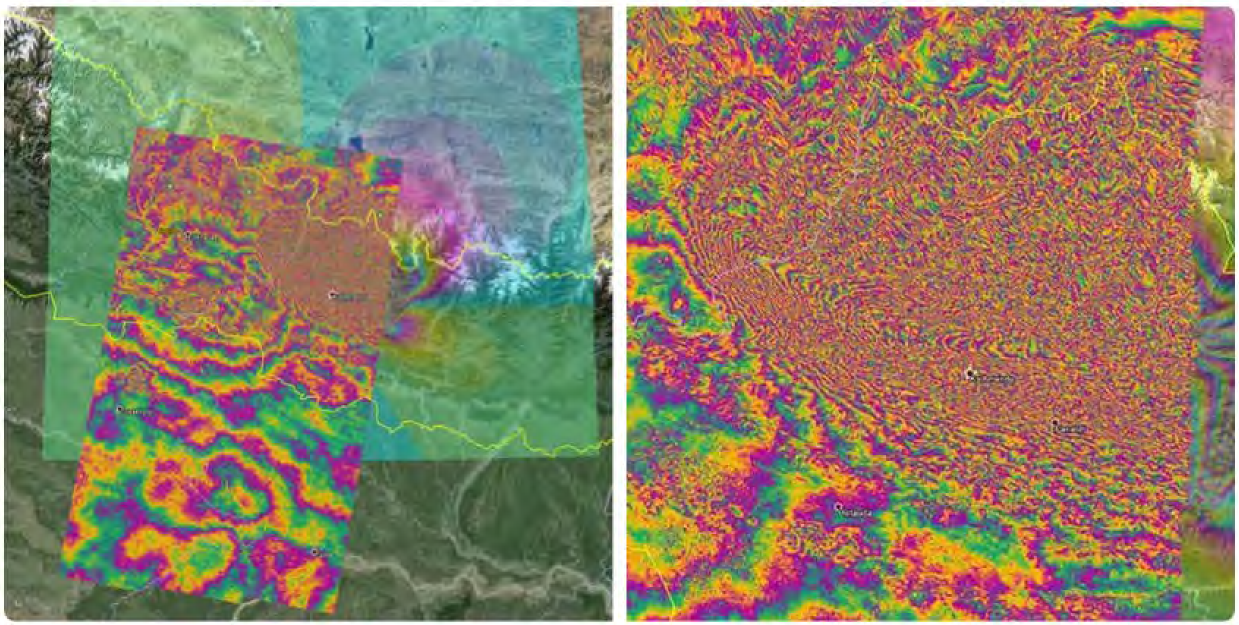


Sentinel-1	Other SAR mission archives
1. Systematic acquisitions for tectonics and volcanoes: “InSAR everywhere all the time”	Haphazard acquisitions (multiple modes, no unified strategy)
2. TOPS: 250 km x 1000+ km: Continental scale InSAR	Small areas imaged, usually less than 100 km swaths.
3. Small perpendicular baselines, acquisitions every 6/12/24 days, ascending and descending -> high coherence	Typically large perpendicular baselines and long gaps between acquisitions -> poor coherence
4. 20 year operational program, designed for InSAR	Stand-alone missions not designed for InSAR
5. Free, full and open data policy, enables mass processing.	Restricted data access, often commercial pricing

Petar Marinković
@pmar

Following

Coseismic #Sentinel1 epicentral interferogram of #NepalQuake available via insarap.org - 34 fringes!



RETWEETS 28 FAVORITES 20

9:08 AM - 29 Apr 2015

This was ~3 hours after ESA posted the data on scihub (~9 hours from acquisition)

Preliminary inspection of Sentinel-1 interferogram told us vital things about the earthquake instantly.
[6 points posted at ~10.35 am on 29 April]

The fact that we have a near-guaranteed response, and we can respond quickly, is a huge benefit from Sentinel-1.

@NERC_COMET
@timwright_leeds
@EwFProject

Tim Wright @timwright_leeds · Apr 29
We will also use the data in @NERC_COMET @EwFProject for mapping damage and landslides. #NepalEarthquake #insarap #Sentinel1 (8/7)
17 5

Tim Wright @timwright_leeds · Apr 29
6. Overall, area at least 120 x100 km moved. #Sentinel-1 data invaluable at this scale. #NepalEarthquake #insarap #Sentinel1 (7/7)
29 4

Tim Wright @timwright_leeds · Apr 29
5. Area north of Kathmandu subsides. Consistent with elastic rebound from shallow thrust #NepalEarthquake #insarap #Sentinel1 (6/7)
30 2

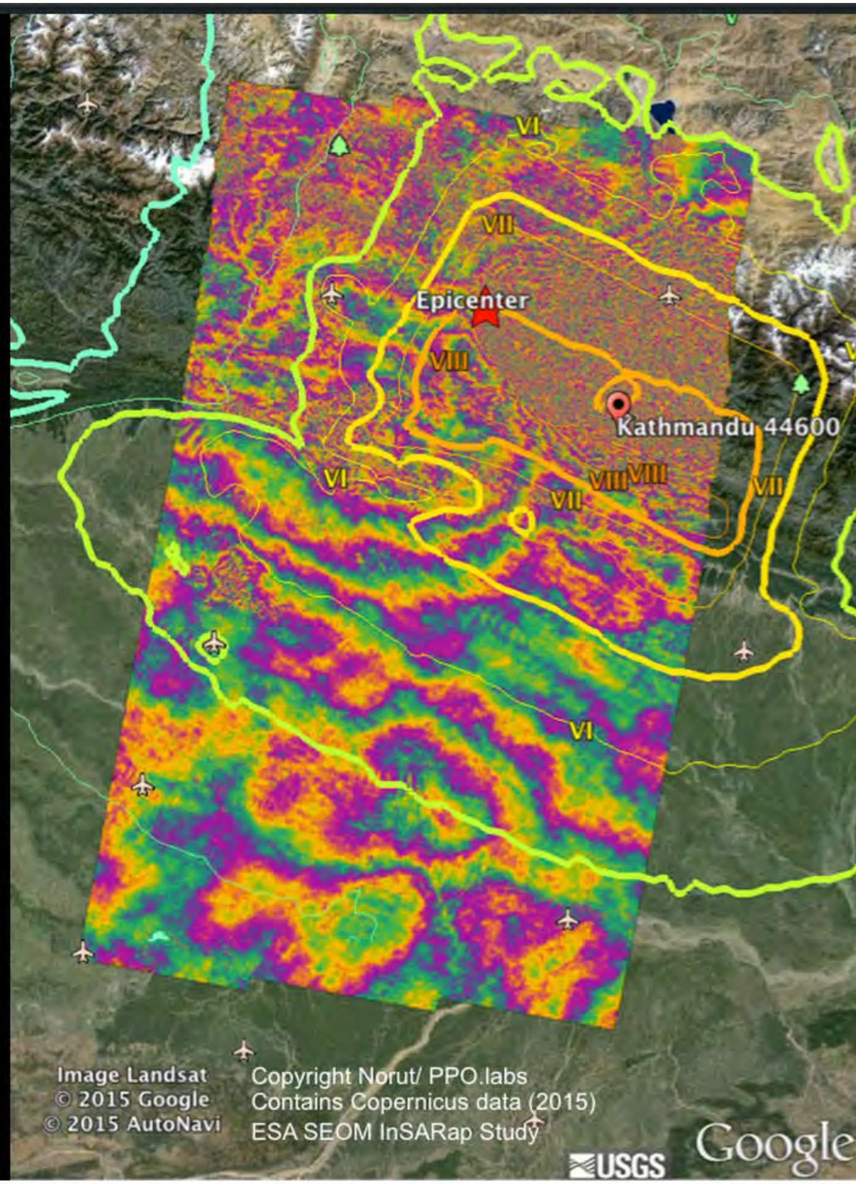
Tim Wright @timwright_leeds · Apr 29
4. The fault did not rupture the surface.
#NepalEarthquake #insarap #Sentinel1 (5/7)
33 3

Tim Wright @timwright_leeds · Apr 29
3. An area at least 120x50 km uplifted, with a maximum greater than 1m.
#NepalEarthquake #insarap #Sentinel1 (4/7)
36 5

Tim Wright @timwright_leeds · Apr 29
2. Peak displacement is very close to Kathmandu; fault under the city slipped significantly. #NepalEarthquake #insarap #Sentinel1 (3/7)
28 1

Tim Wright @timwright_leeds · Apr 29
1. Quake ruptured east from Epicentre, confirming seismology
#NepalEarthquake #insarap #Sentinel1
29 2

Tim Wright @timwright_leeds · Apr 29
Quick interpretation of of 1st #Sentinel1 interferogram for Nepal quake (from insarap.org)
#NepalEarthquake #insarap (1/7)
20 1

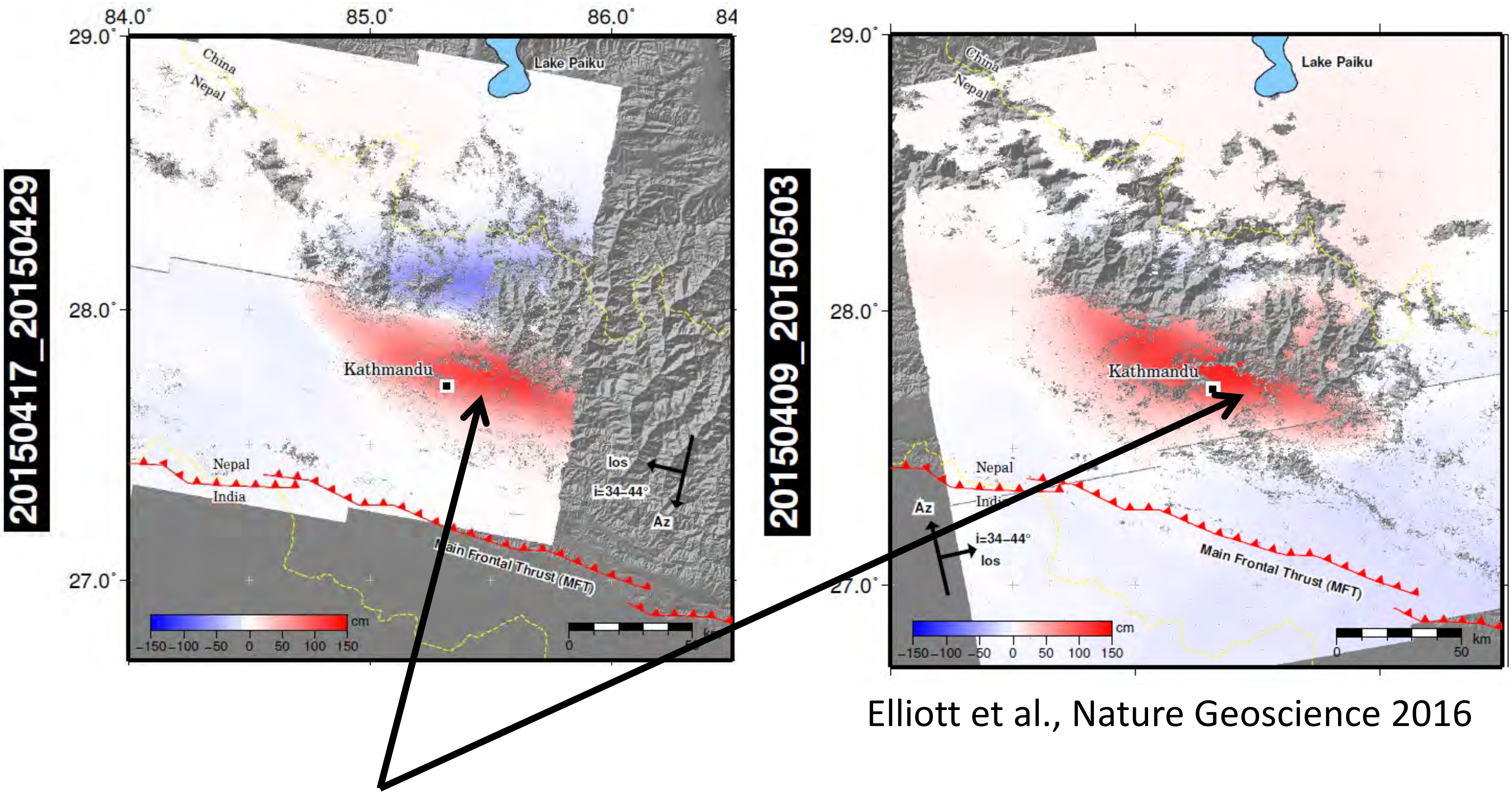


David Bekaert @SARscience · Apr 29

Overlaid the @USGS #NepalQuake shake map with new coseismic #sentinel1 interferogram of @NorutNRI @pmar. @EwFProject

52 13

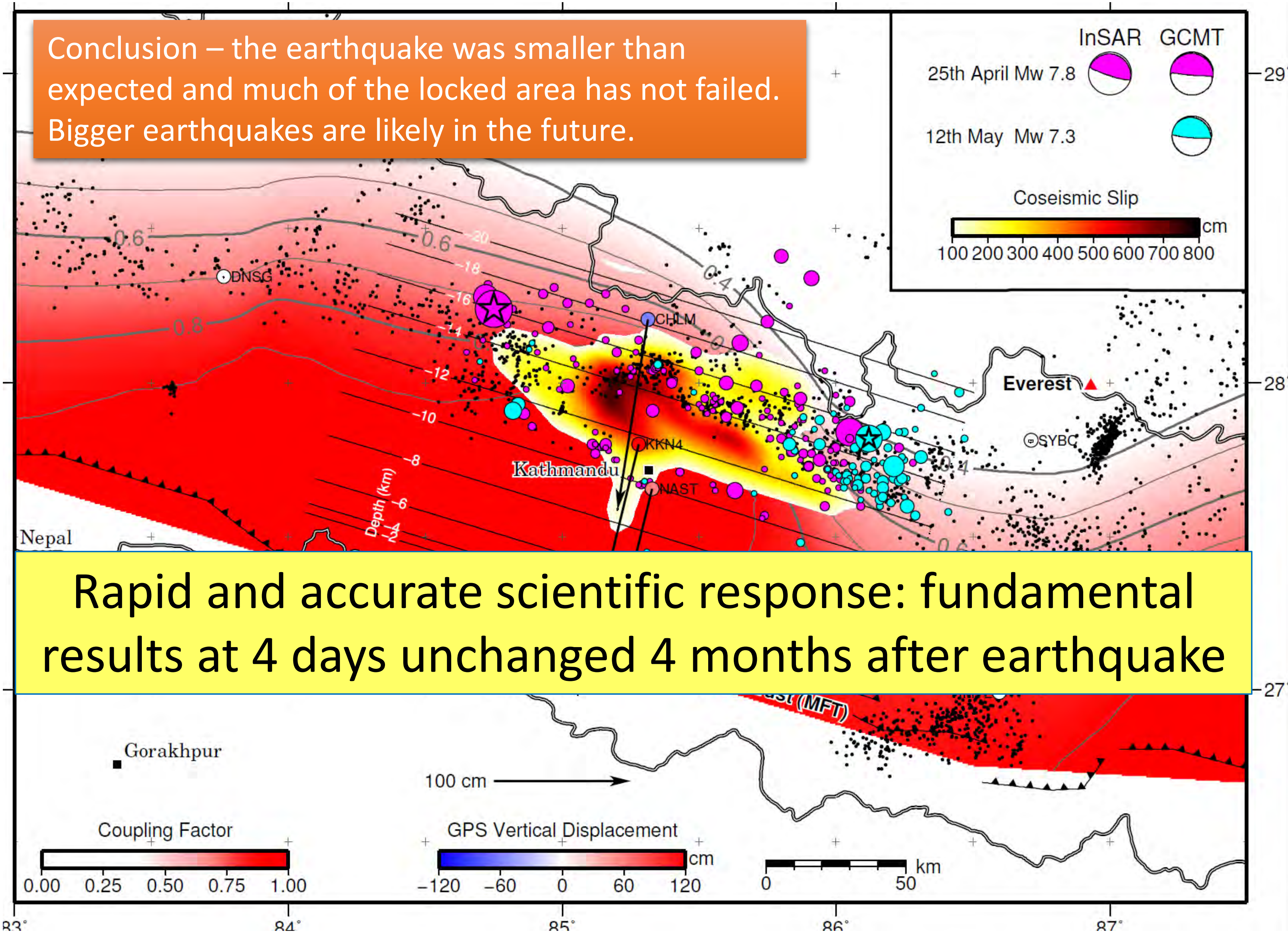
Tidied up, unwrapped S1 interferograms



Elliott et al., Nature Geoscience 2016

Area around Kathmandu moved towards satellite by over 1 m

Conclusion – the earthquake was smaller than expected and much of the locked area has not failed. Bigger earthquakes are likely in the future.



Rapid and accurate scientific response: fundamental results at 4 days unchanged 4 months after earthquake

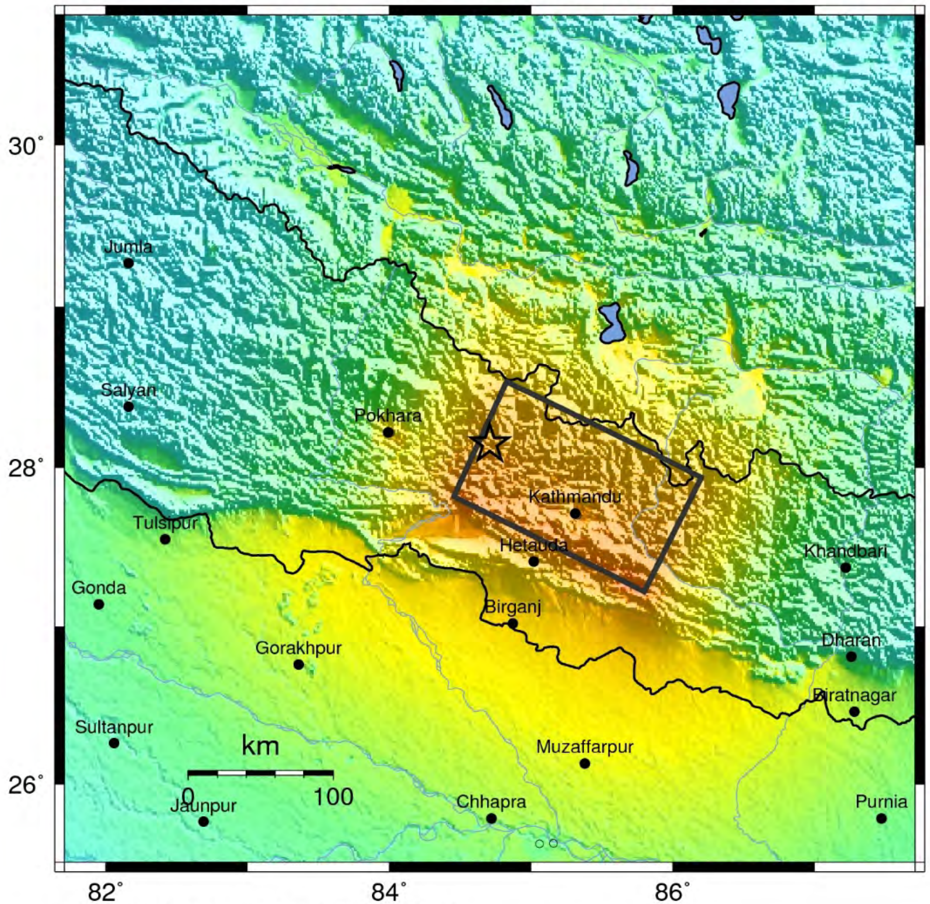
Elliott et al., Nature Geoscience 2016

Initial location and magnitude comes rapidly from seismology…

v1 EQ + 19 minutes
v2 EQ + 52 minutes
v3 EQ + 83 minutes
v4 EQ + 2 hours
v5 EQ + 4 hours
v6 EQ + 15 hours

USGS ShakeMap : NEPAL

Apr 25, 2015 06:11:26 UTC   M 7.8   N28.15 E84.71   Depth: 15.0km   ID:us20002926



Map Version 6 Processed 2015-04-25 21:32:54 UTC

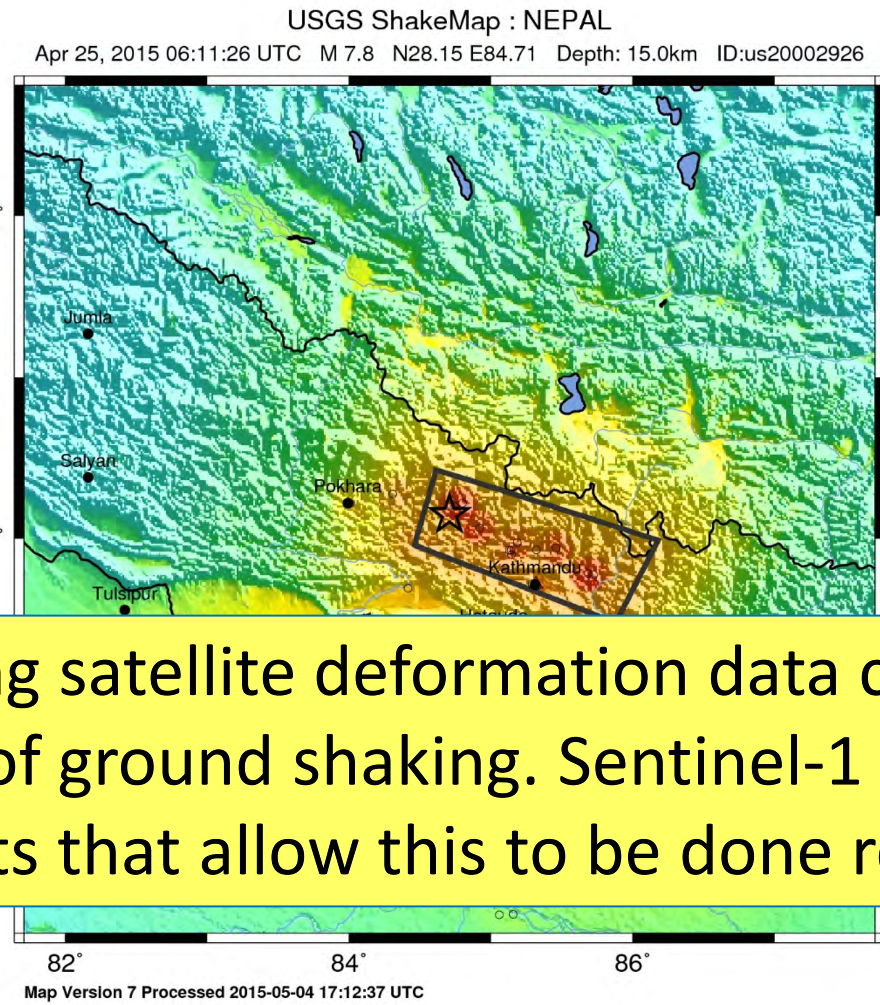
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

Thanks to Richard Briggs, Gavin Hayes, Bill Barnhard, USGS

Initial location and magnitude comes rapidly from seismology…

- v1 EQ + 19 minutes
- v2 EQ + 52 minutes
- v3 EQ + 83 minutes
- v4 EQ + 2 hours
- v5 EQ + 4 hours
- v6 EQ + 15 hours
- v7 EQ + 10 days



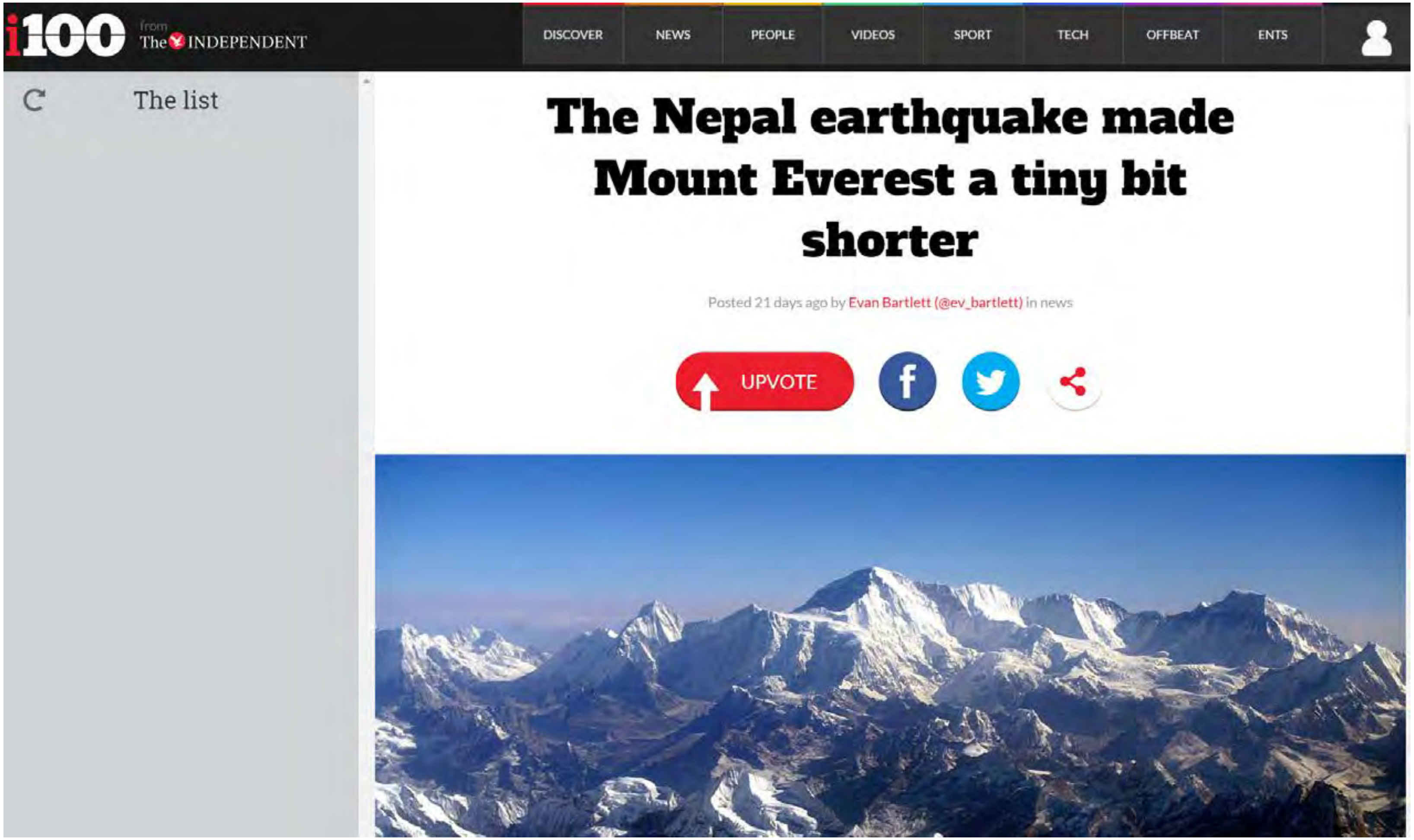
Incorporating satellite deformation data changes the predictions of ground shaking. Sentinel-1 can provide the results that allow this to be done routinely.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

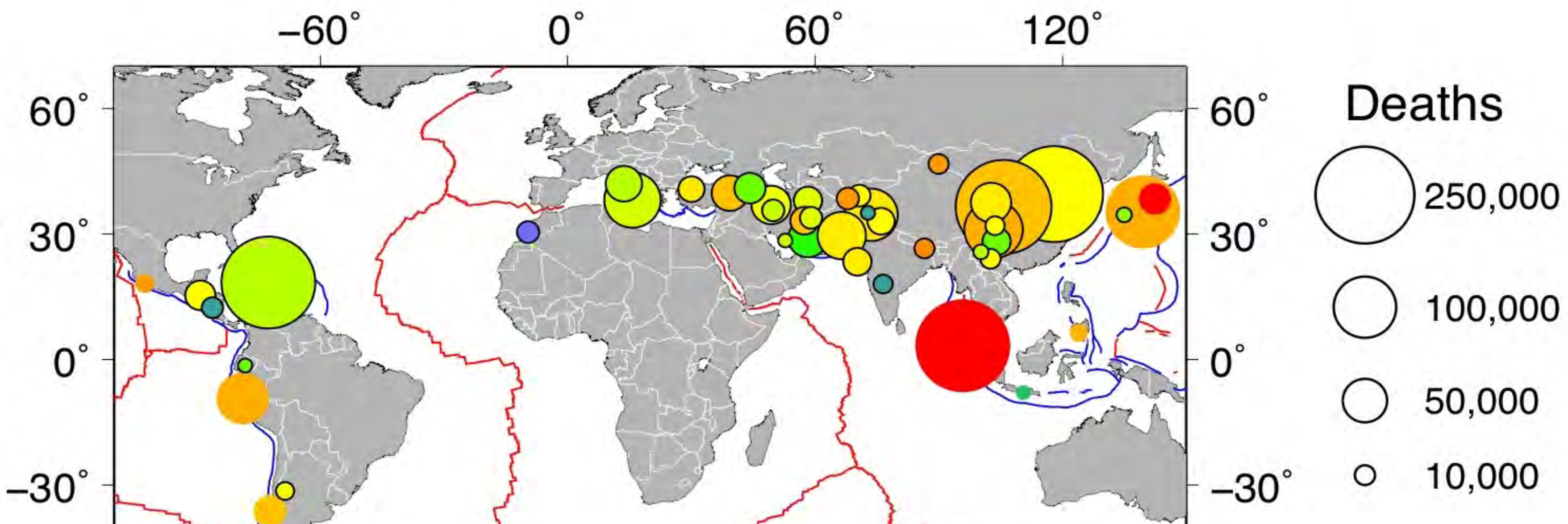
Thanks to Richard Briggs, Gavin Hayes, Bill Barnhard, USGS

Media obsessed about whether Everest went up or down!



Dull answer: from InSAR we can only say it hasn't moved much
(The shrinking story came from a very early model based on GPS)

Mitigation?

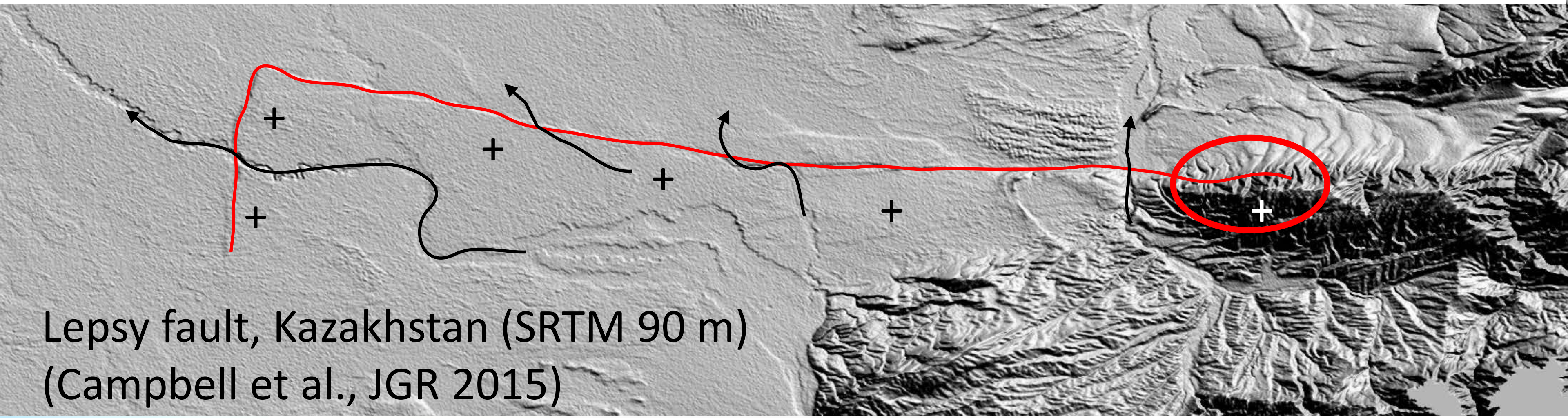


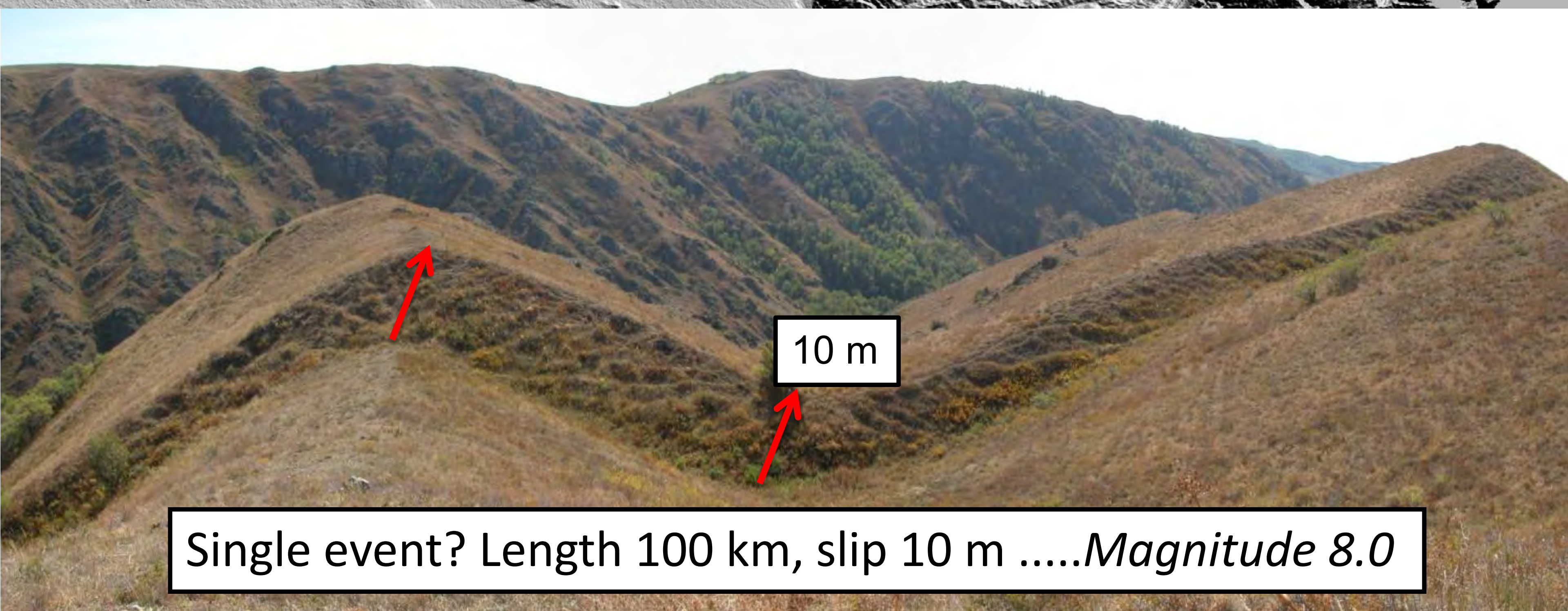
We don’t know where the killer faults are, and which ones are likely to fail.

100 years of deadly earthquakes

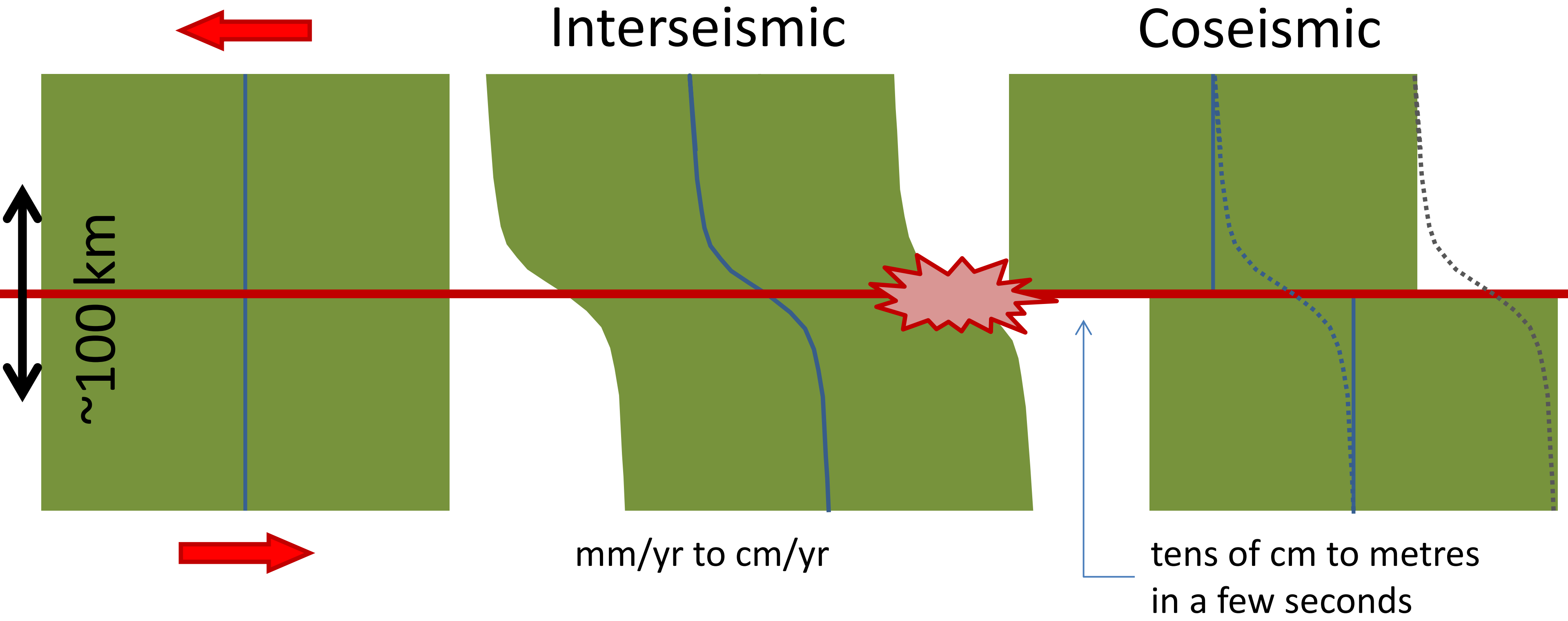
Figure from http://comet.nerc.ac.uk/ earthquake workshop report

Identifying previously unknown faults with high-resolution imagery and DEMs



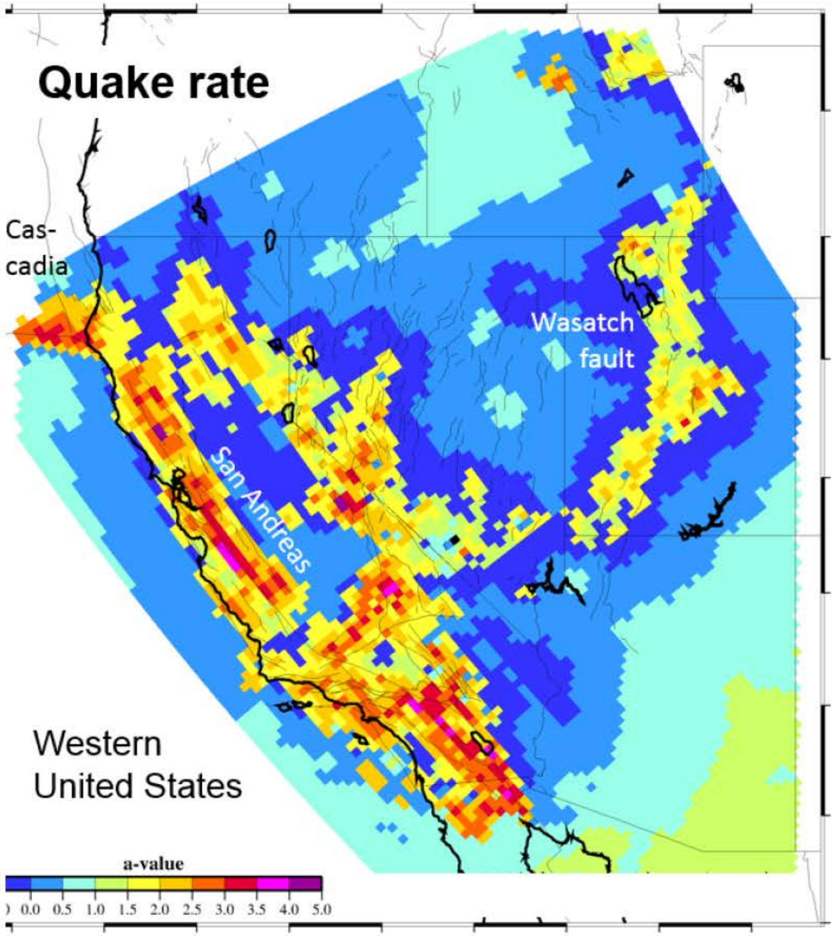


The earthquake cycle

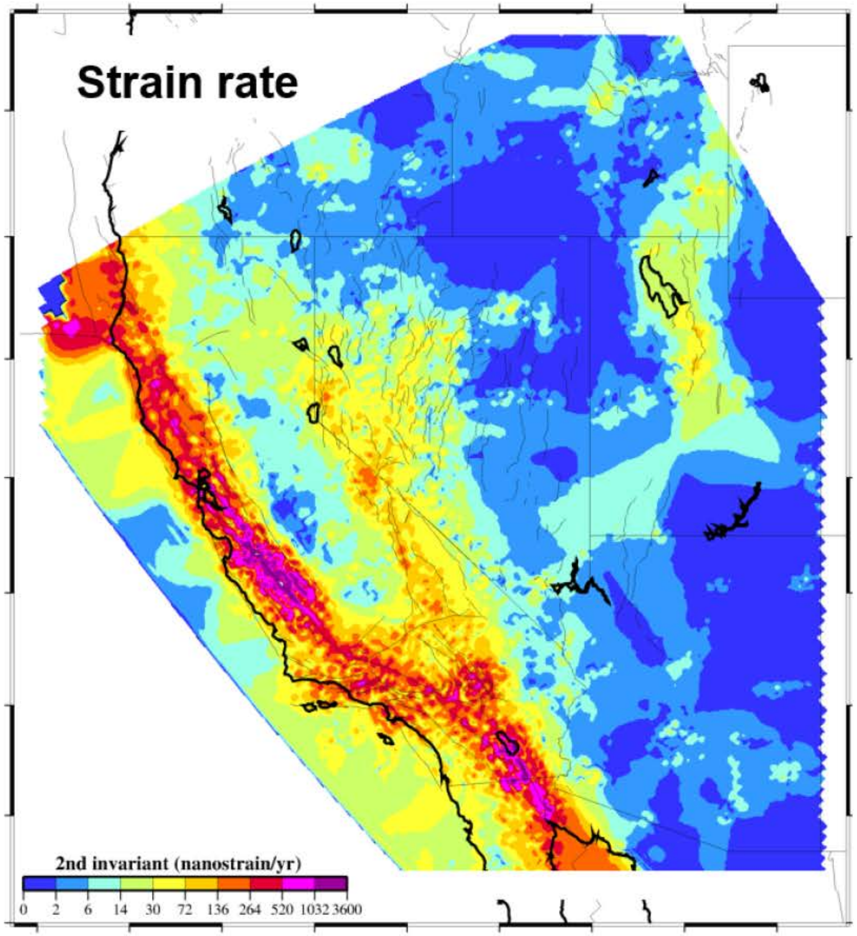


- Although they cannot be predicted, earthquakes are usually preceded by the slow build up of tectonic strain.
- Repeated geodetic measurements can be combined to measure surface displacements at the mm level over large areas.

Tectonic Strain & Seismic Hazard



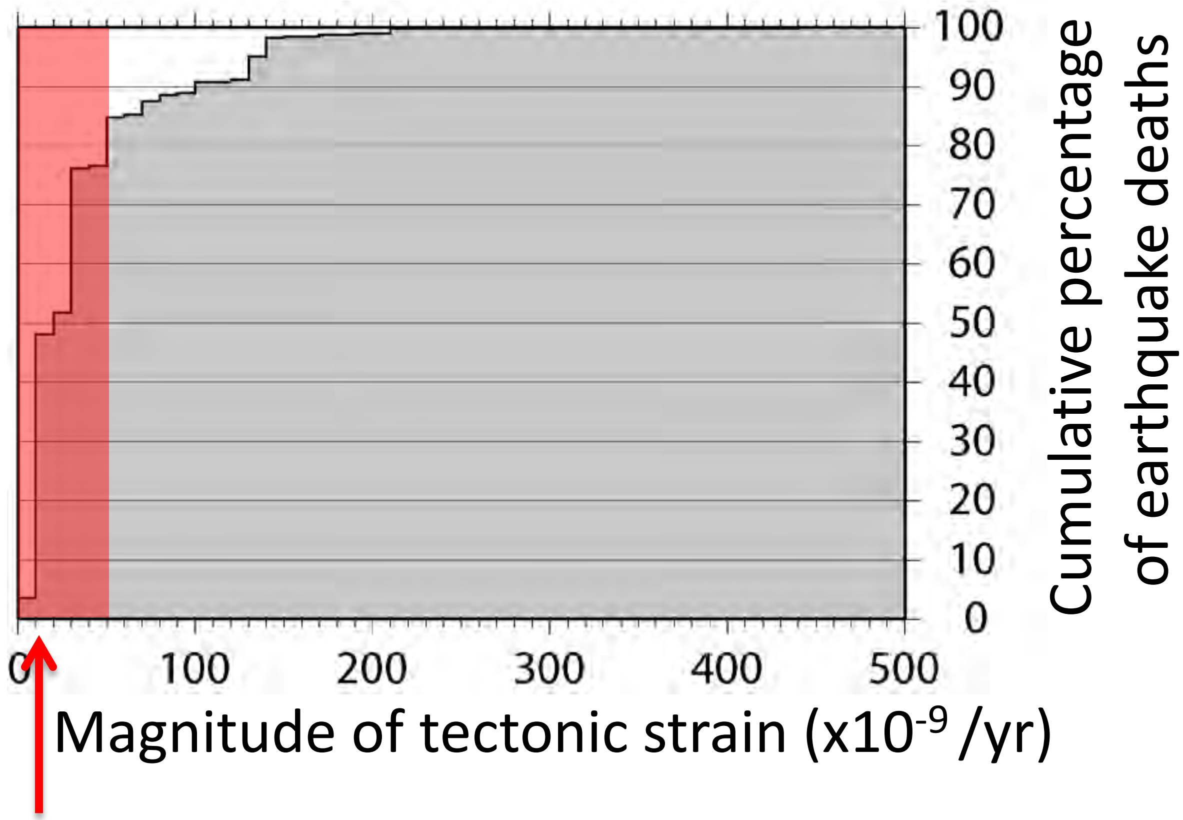
Gutenberg-Richter a-value from declustered ANSS catalog (Arnaud Mignan, ETH Zurich)



2000-2011 GPS velocities used by Kreemer et al for the GEM Strain Rate Model

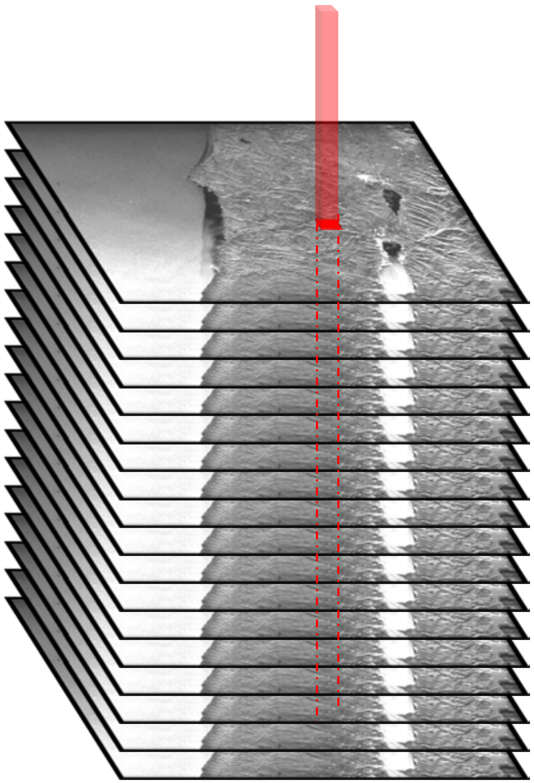
Figure from Corné Kreemer/Ross Stein/GEM

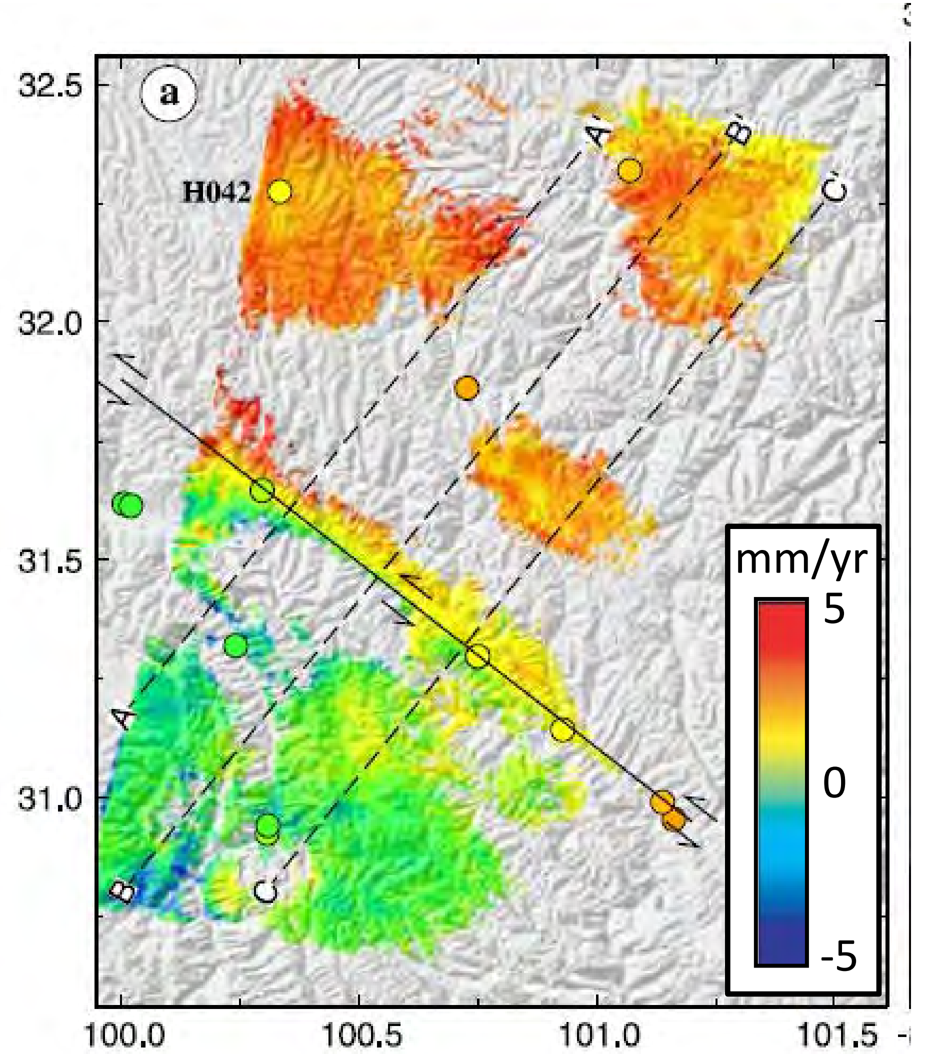
Accuracy Requirements and Earthquake Hazard



- 96% of all earthquake deaths are in regions with strain rates greater than 1mm/yr over 100 km (10^{-8}/yr)
- 77% of fatalities occur where deformation rates are ≤ 5 mm/yr over 100 km.

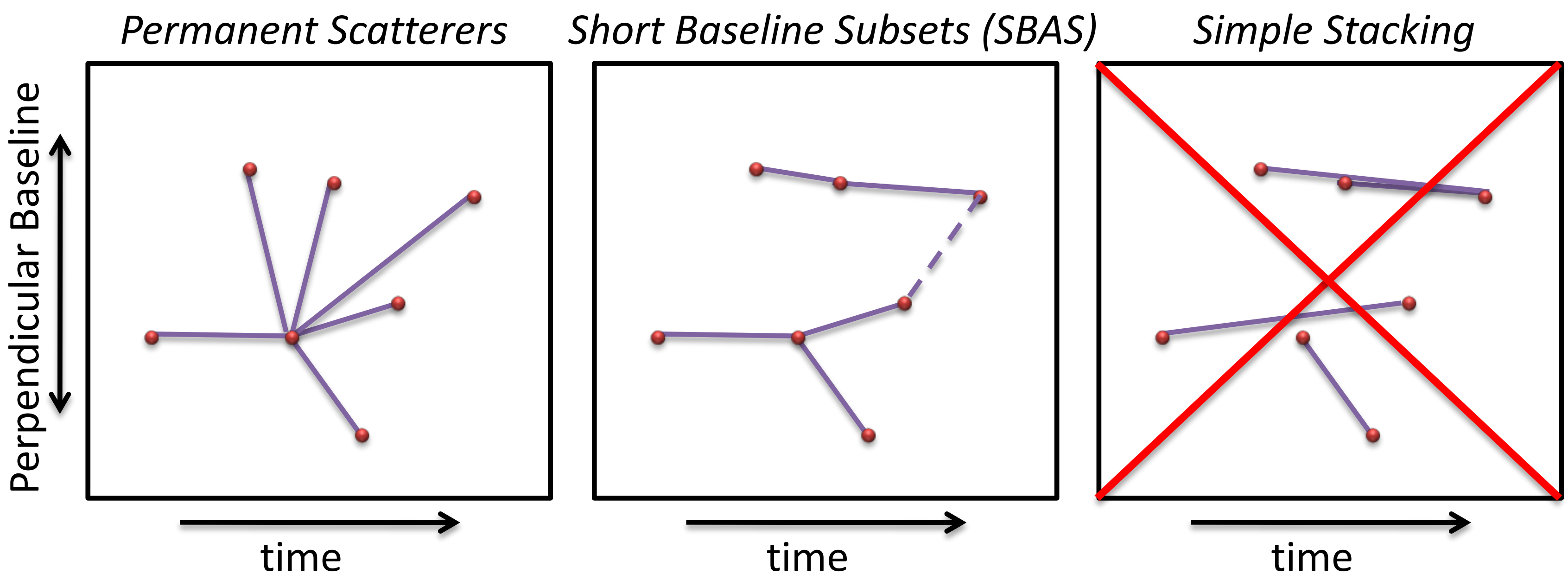
Achieving 1 mm/yr accuracy





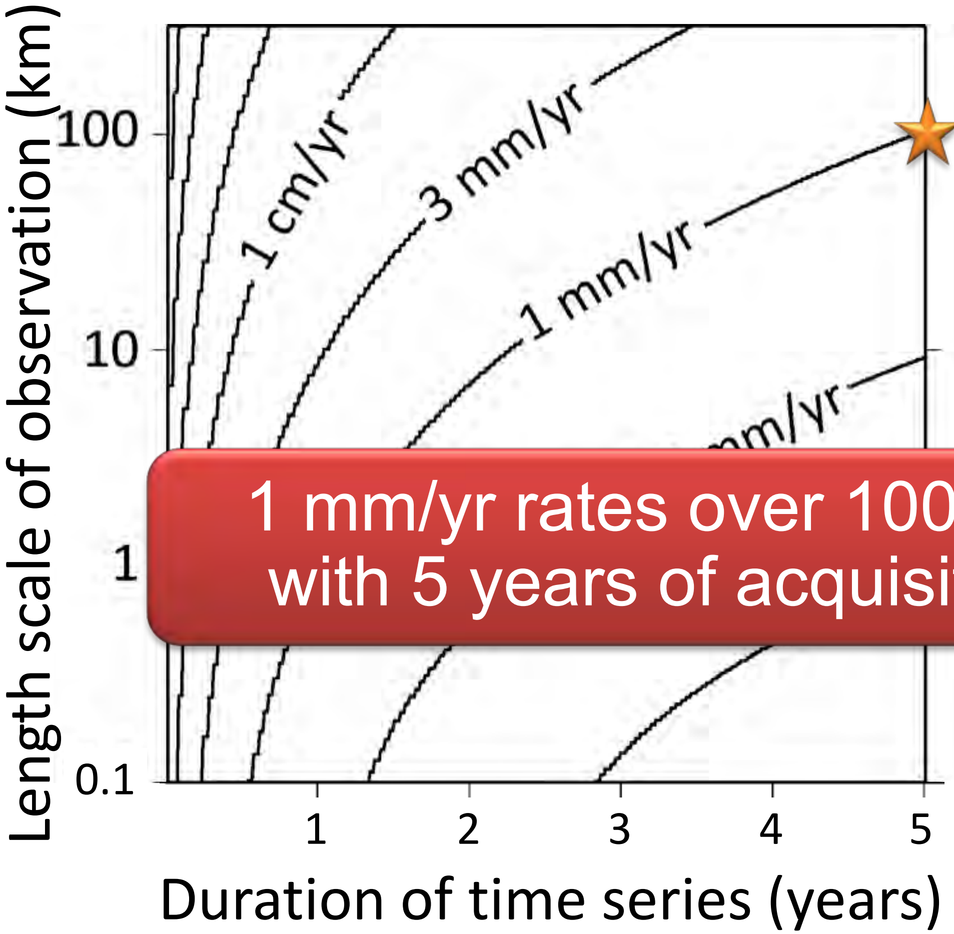
Wang, Wright et al, 2008

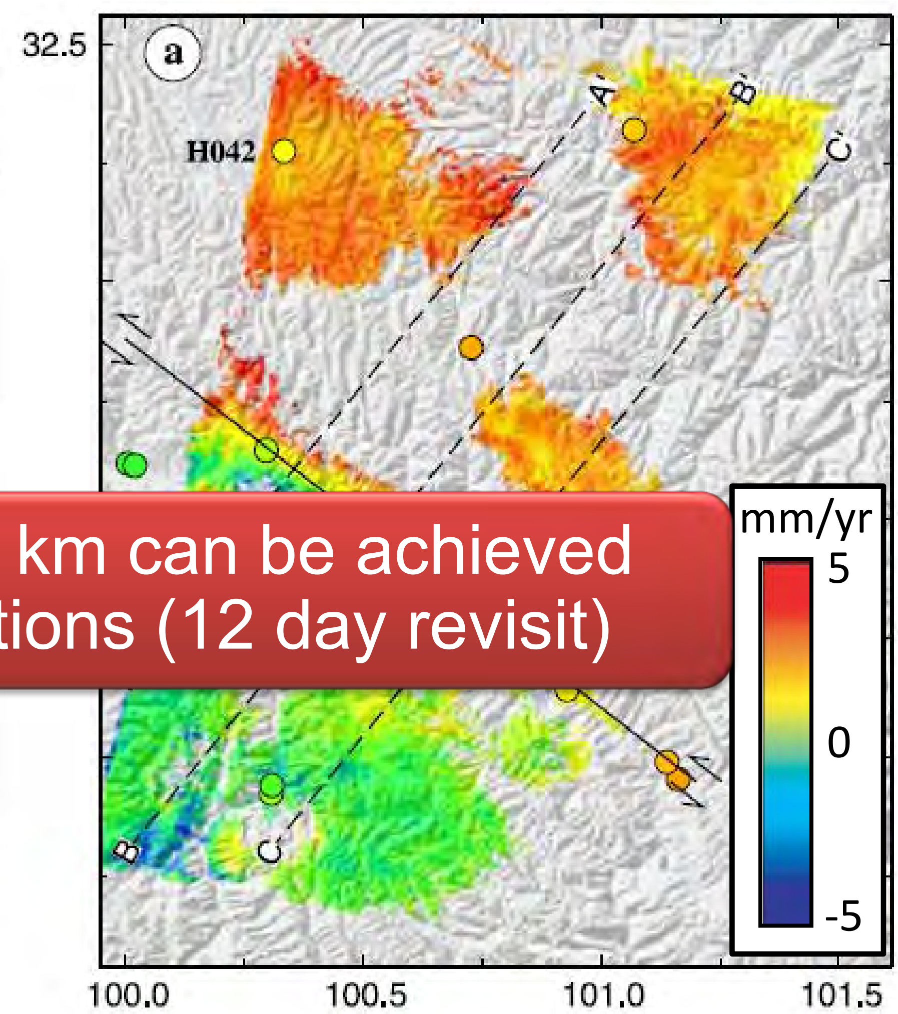
Combining Multiple Acquisitions to determine time series and/or linear deformation rates



Errors are minimised with a connected network, since noise terms are associated with individual acquisitions not interferograms.

Achieving 1 mm/yr accuracy

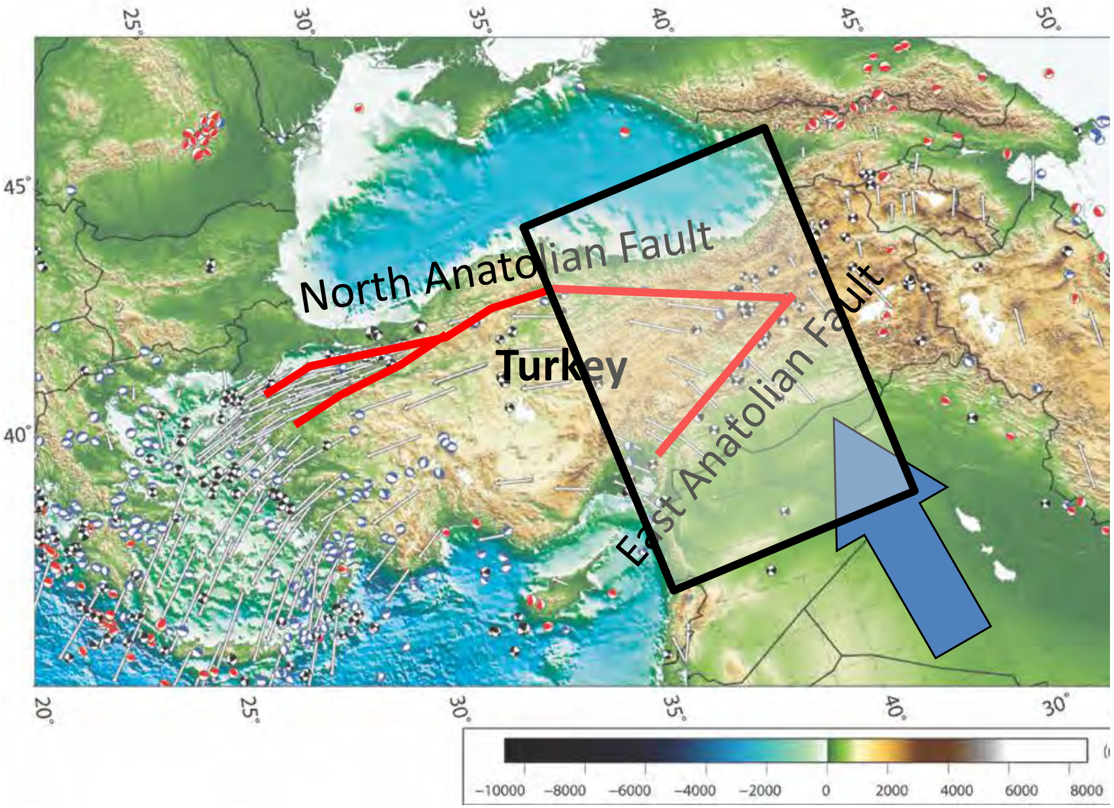


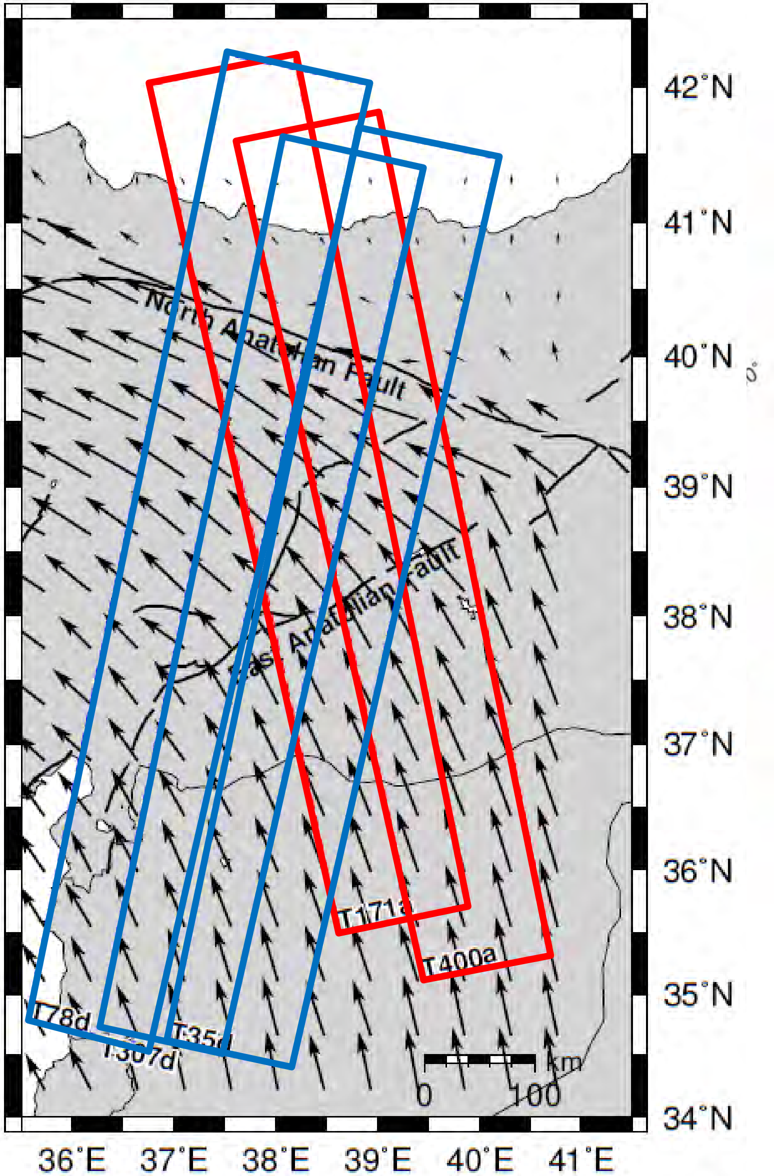


1 mm/yr rates over 100 km can be achieved with 5 years of acquisitions (12 day revisit)

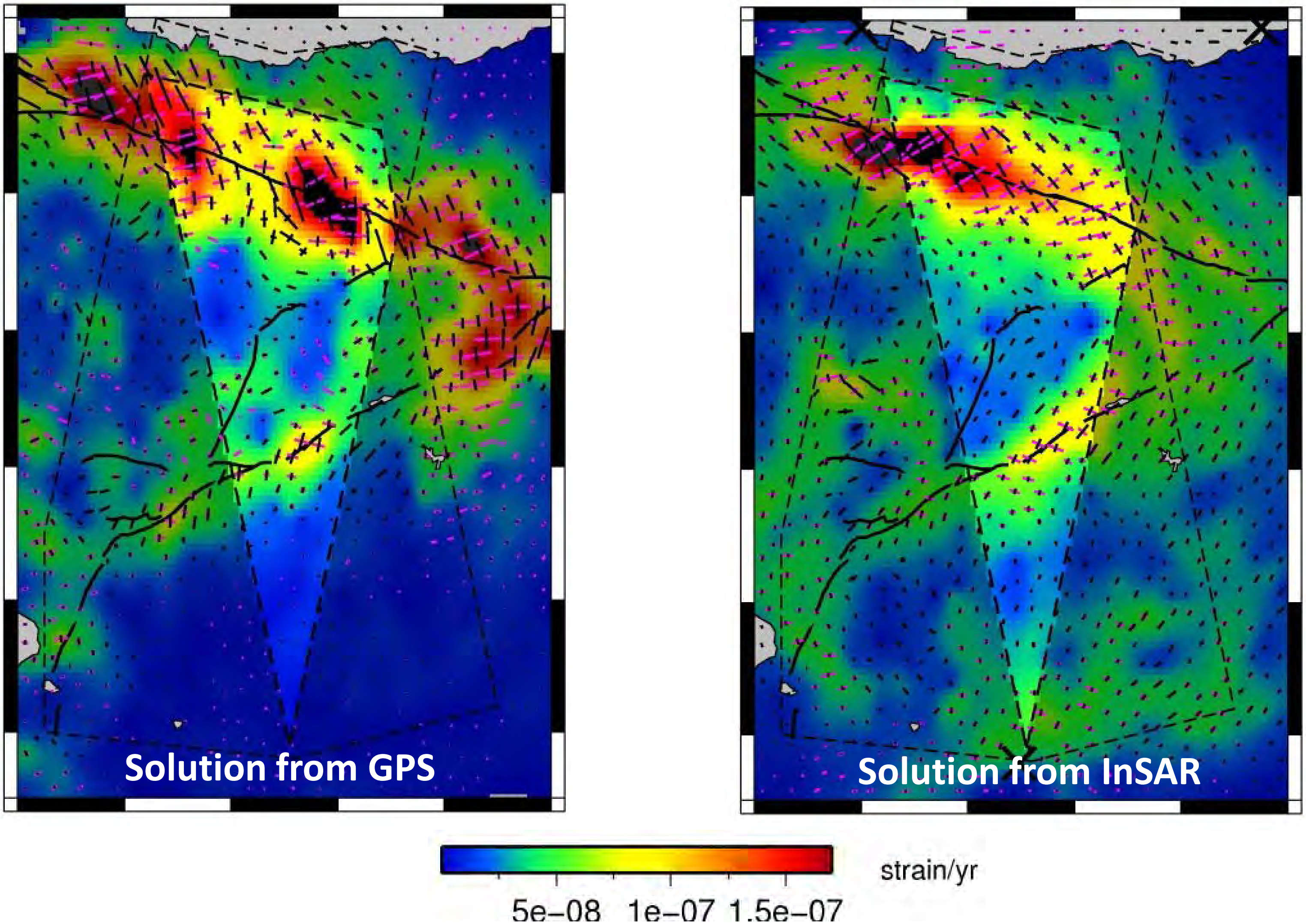
Wang, Wright et al, 2008

Example: Strain mapping in E. Turkey





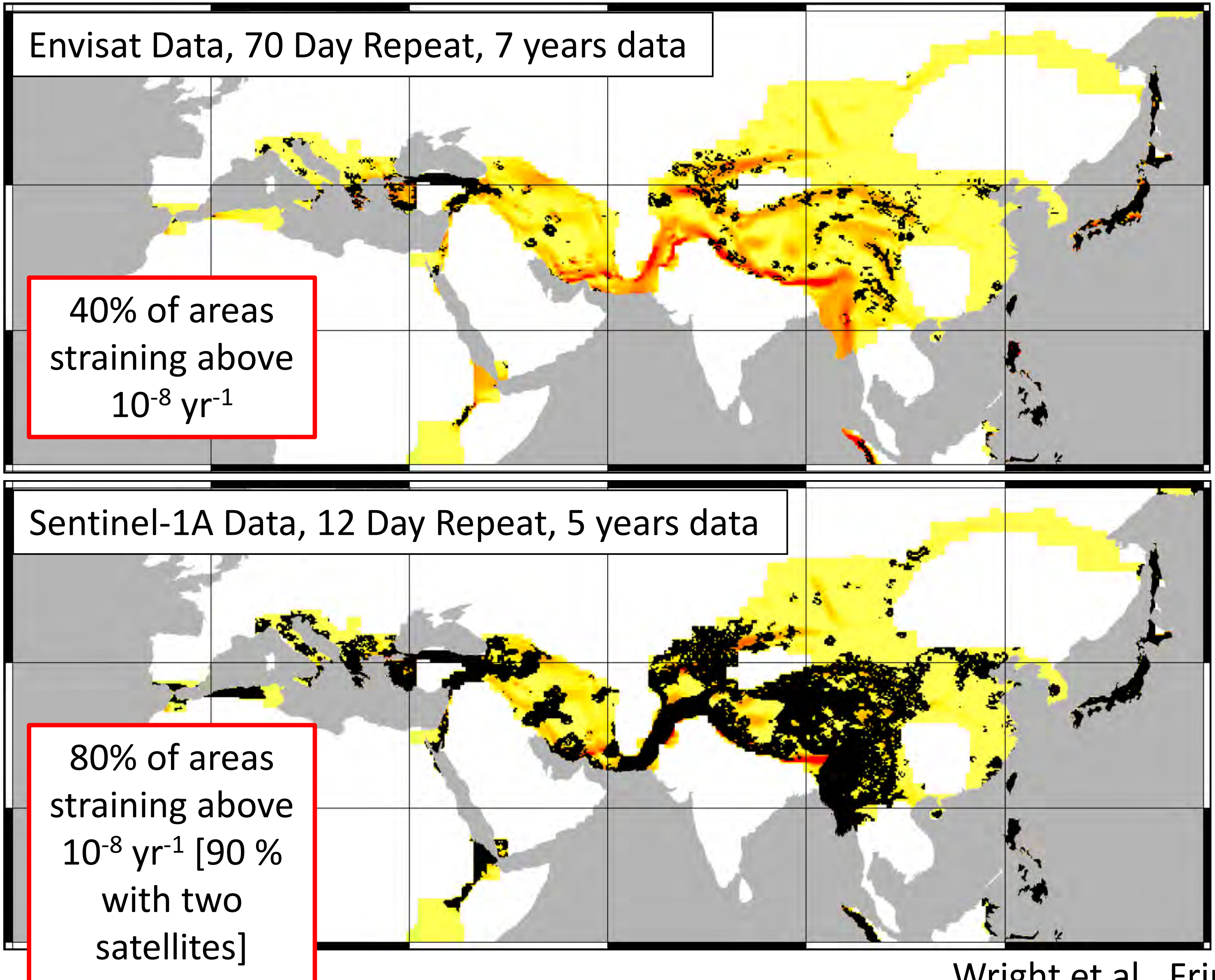
Using InSAR to Map Strain in Eastern Turkey



Work described in Walters et al., JGR 2014; Methods in Wang and Wright, GRL 2012

In COMET, we plan to use Sentinel-1 data acquired over the next 5 years to build a high resolution global map of tectonic strain.

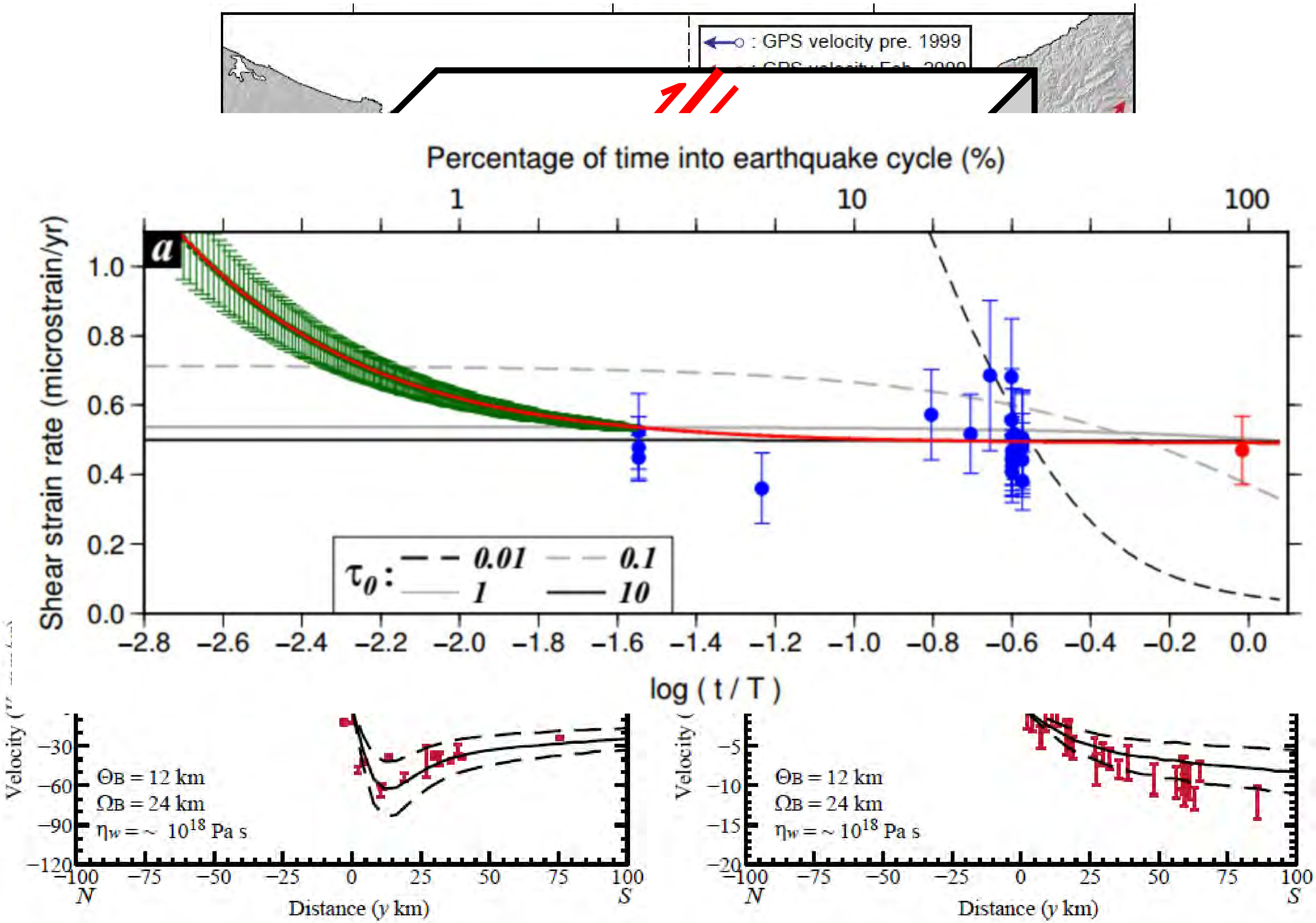
How much better than existing missions?



Wright et al., Fringe 2011

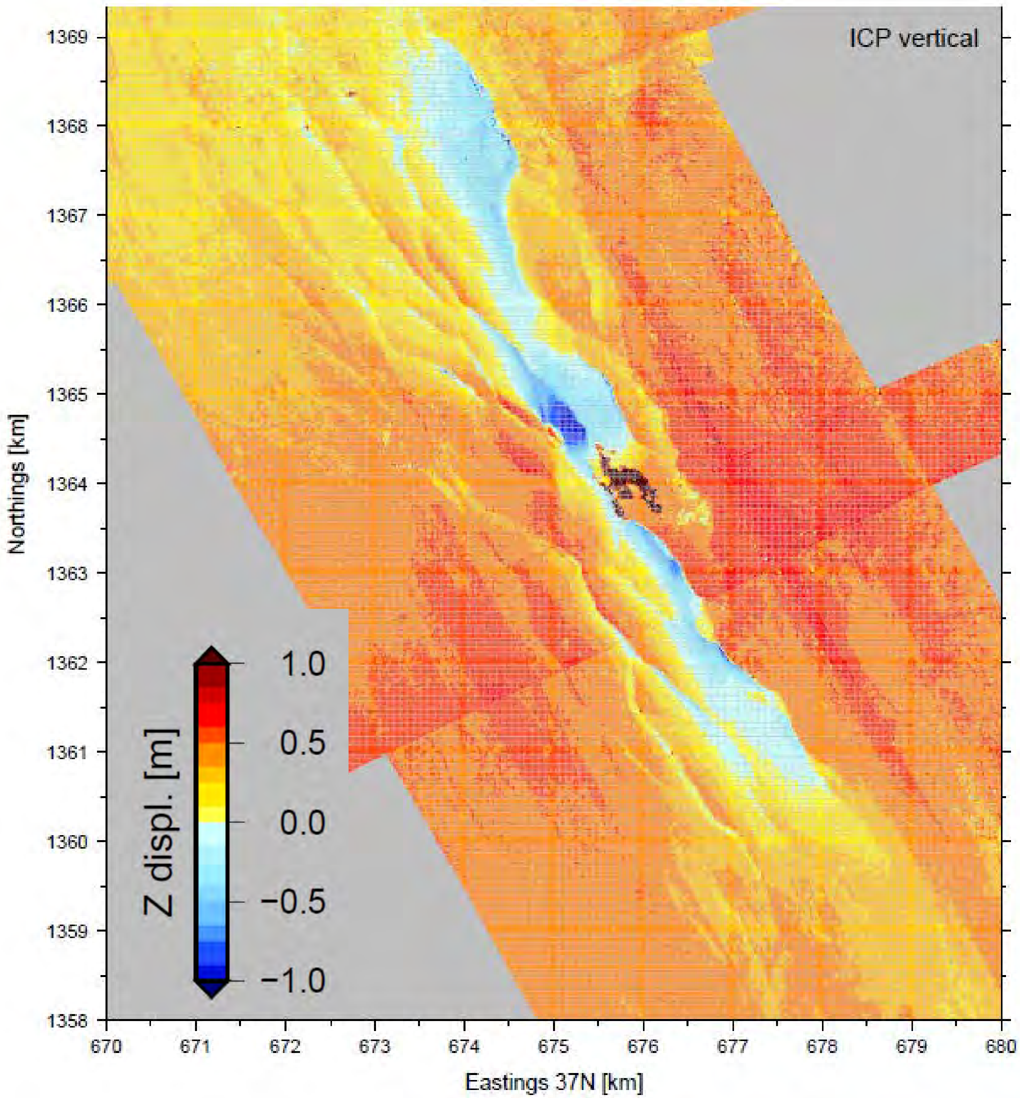
A few science questions…

Are short-term strain observations meaningful?



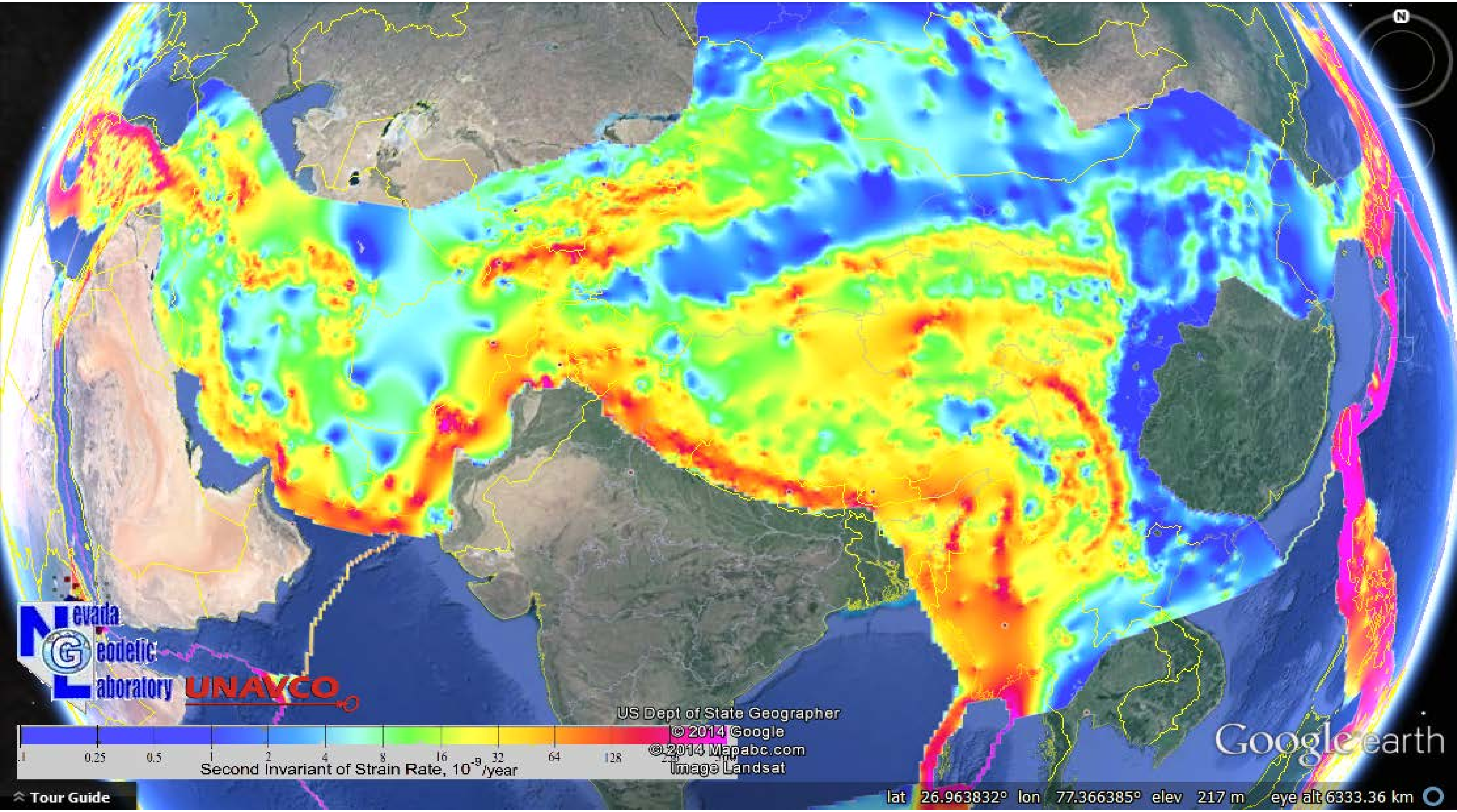
Yamasaki, Wright and Houseman (JGR 2014)

How do faults link and grow?

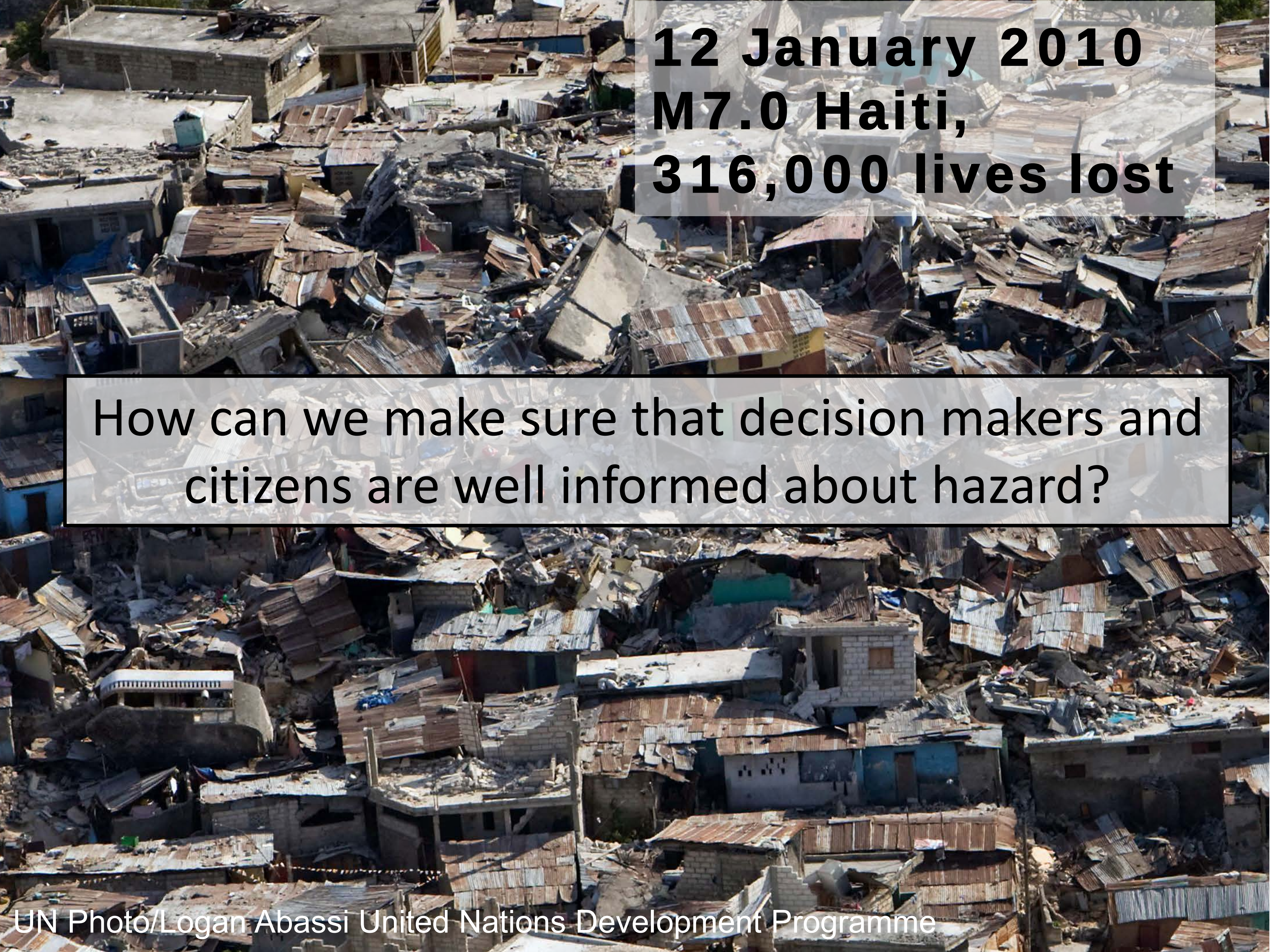


Vertical movement in Afar between October 2009 and November 2012.
Barbara Hofmann PhD thesis (2014)

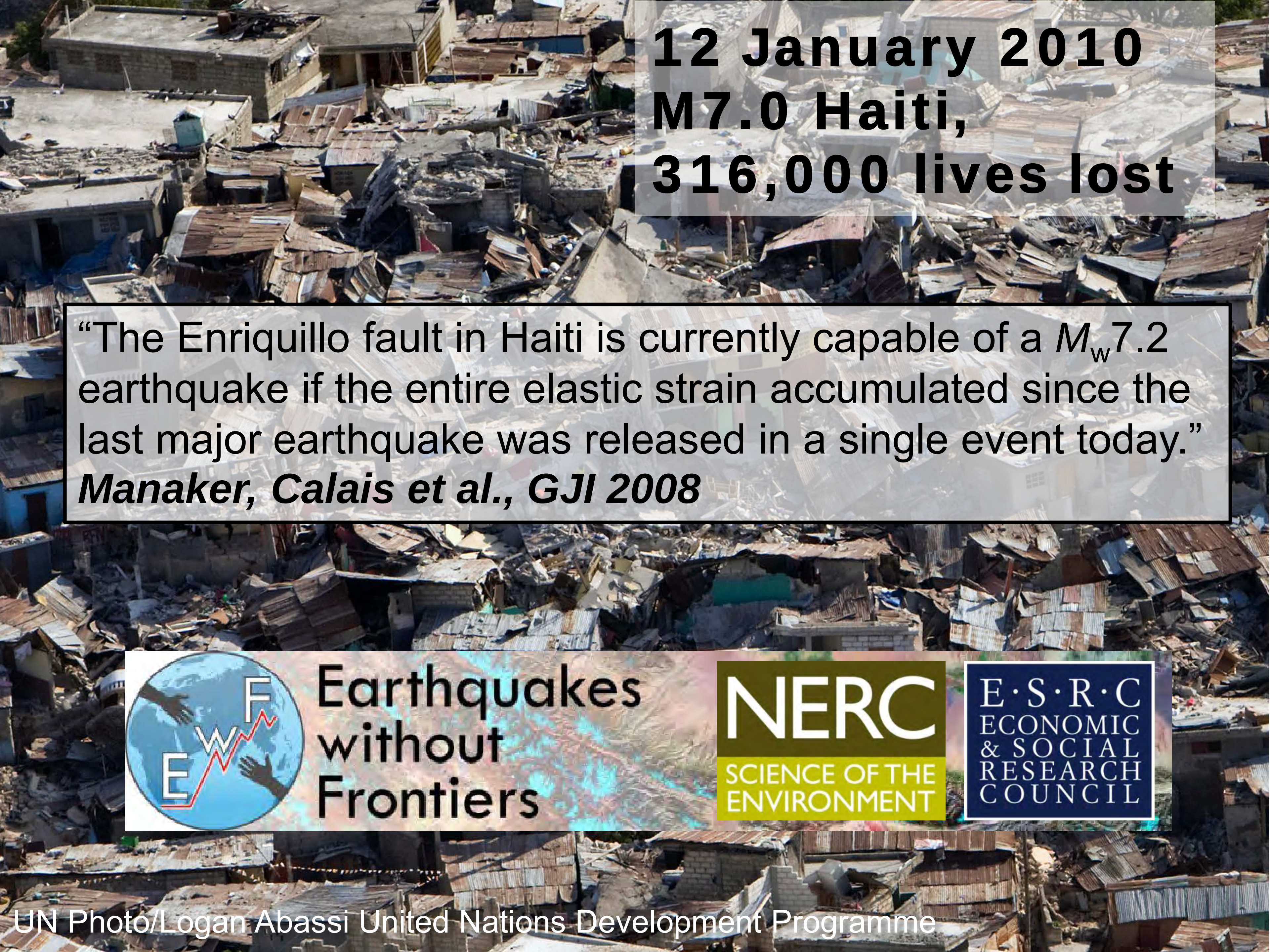
What controls the distribution of strain (and earthquakes) in the continents?



Data from http://gsrm2.unavco.org



UN Photo/Logan Abassi United Nations Development Programme


12 January 2010
M7.0 Haiti,
316,000 lives lost
“The Enriquillo fault in Haiti is currently capable of a M_w7.2 earthquake if the entire elastic strain accumulated since the last major earthquake was released in a single event today.”
Manaker, Calais et al., GJI 2008
Earthquakes without Frontiers
NERC
SCIENCE OF THE ENVIRONMENT
E·S·R·C
ECONOMIC & SOCIAL RESEARCH COUNCIL
UN Photo/Logan Abassi United Nations Development Programme

Earthquakes without Frontiers

NERC SCIENCE OF THE ENVIRONMENT

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http://ewf.nerc.ac.uk/ *twitter: @ewfProject*

Earthquakes without Frontiers

NERC SCIENCE OF THE ENVIRONMENT

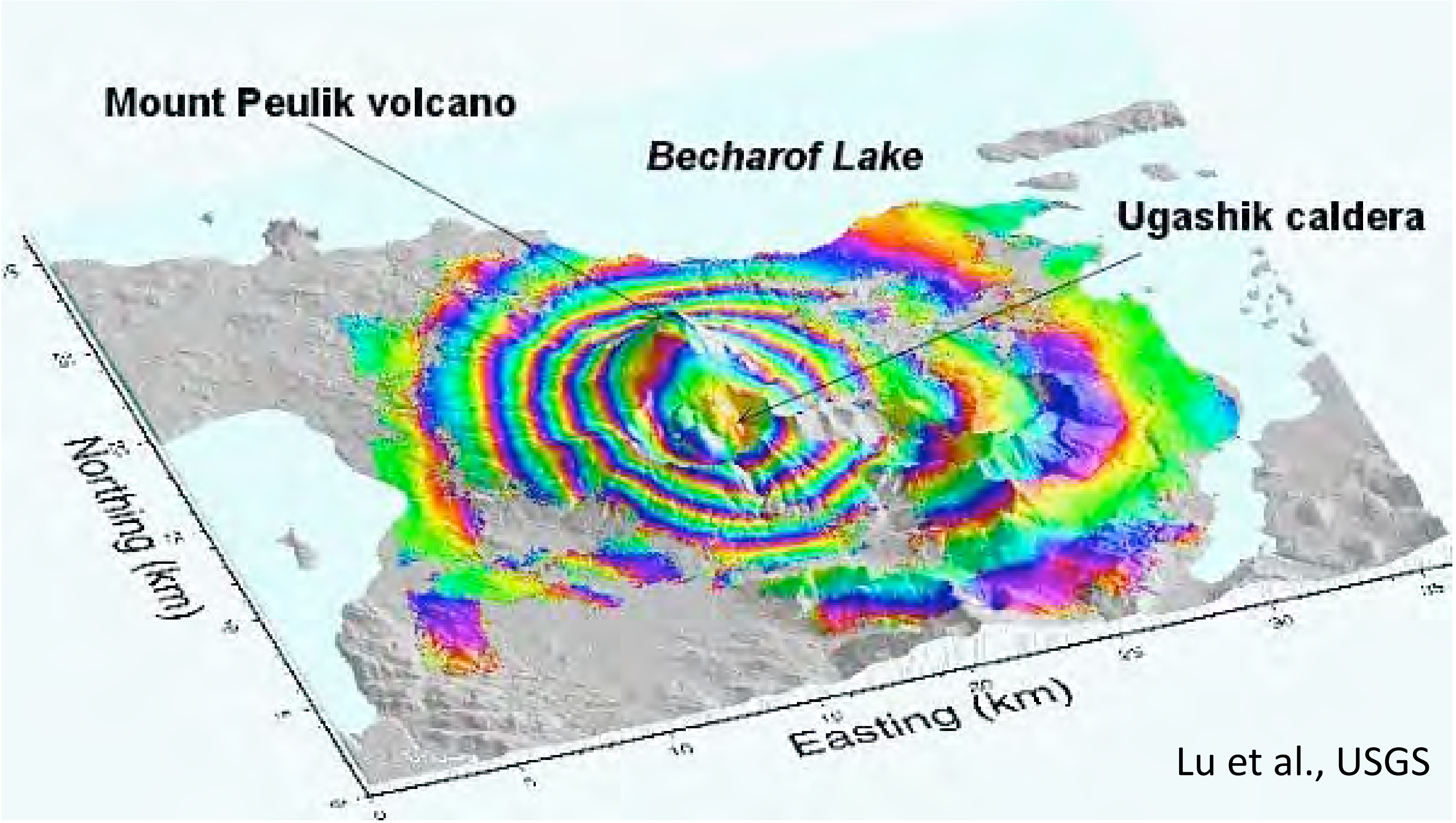
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

http://ewf.nerc.ac.uk/ twitter: @ewfProject

Law on the Regeneration of Areas Under Disaster Risk (2012):

- all buildings that are not up to current earthquake risk standards will be demolished.
- 6.5 million high risk houses will be rebuilt over the next two decades.

Part 2: Using EO for volcanology



Lu et al., USGS

What do volcanologists want to know?

Q1 Where is the magma?

Q2 Has a volcano erupted?

Q3 How much has erupted?

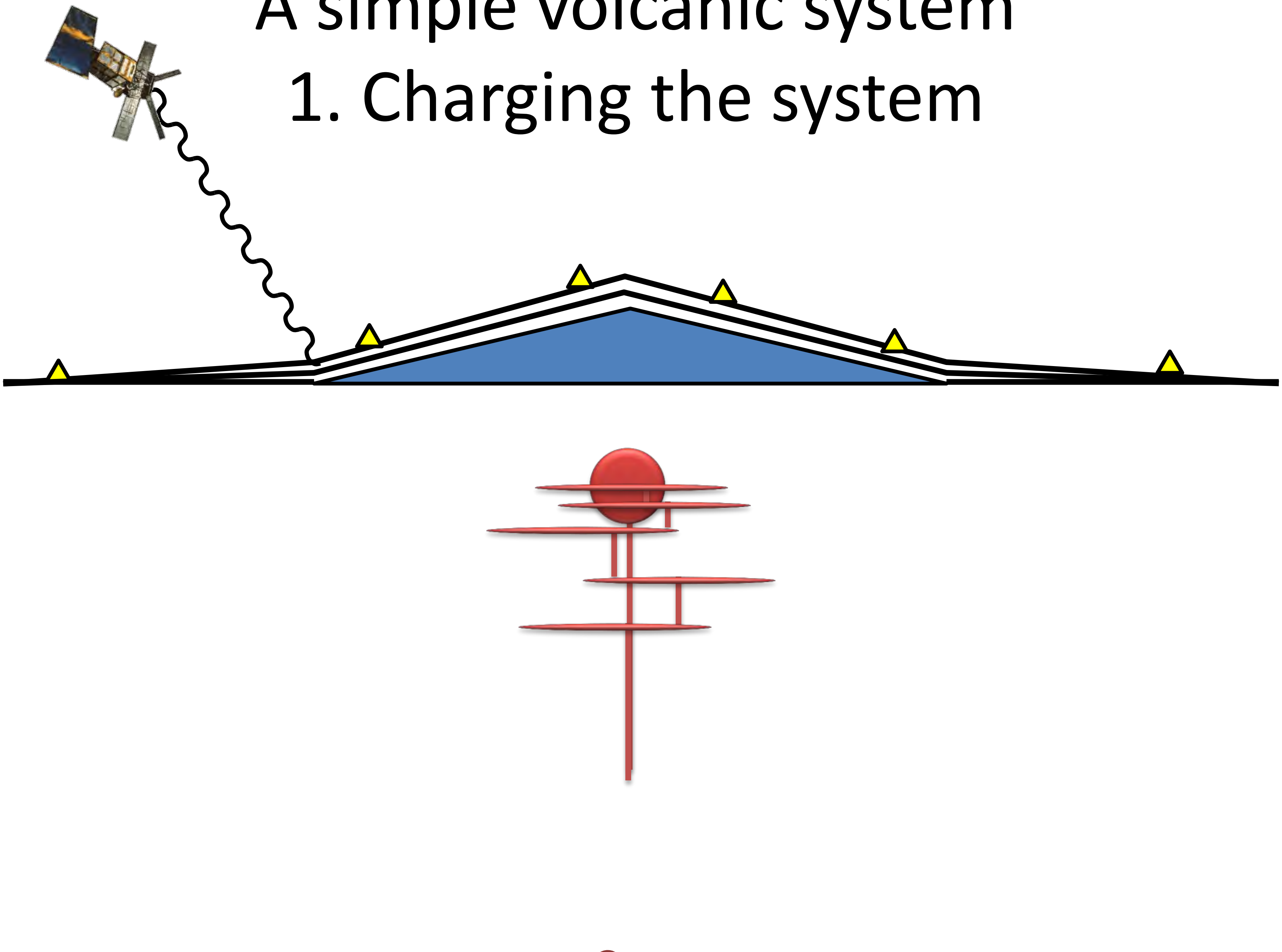
Q4 What will happen next?

Q5 What is the probability of a volcano erupting?

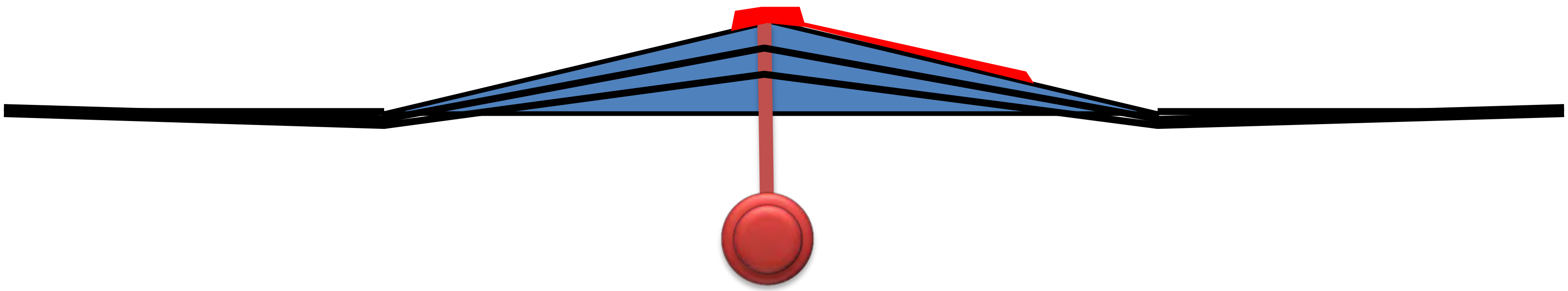
EO data critical in answering these questions

Q1 Where is the magma?

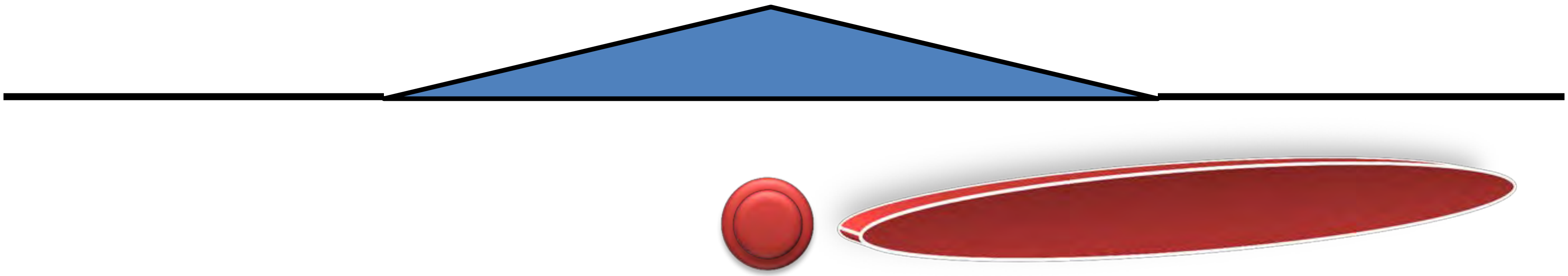
A simple volcanic system
1. Charging the system

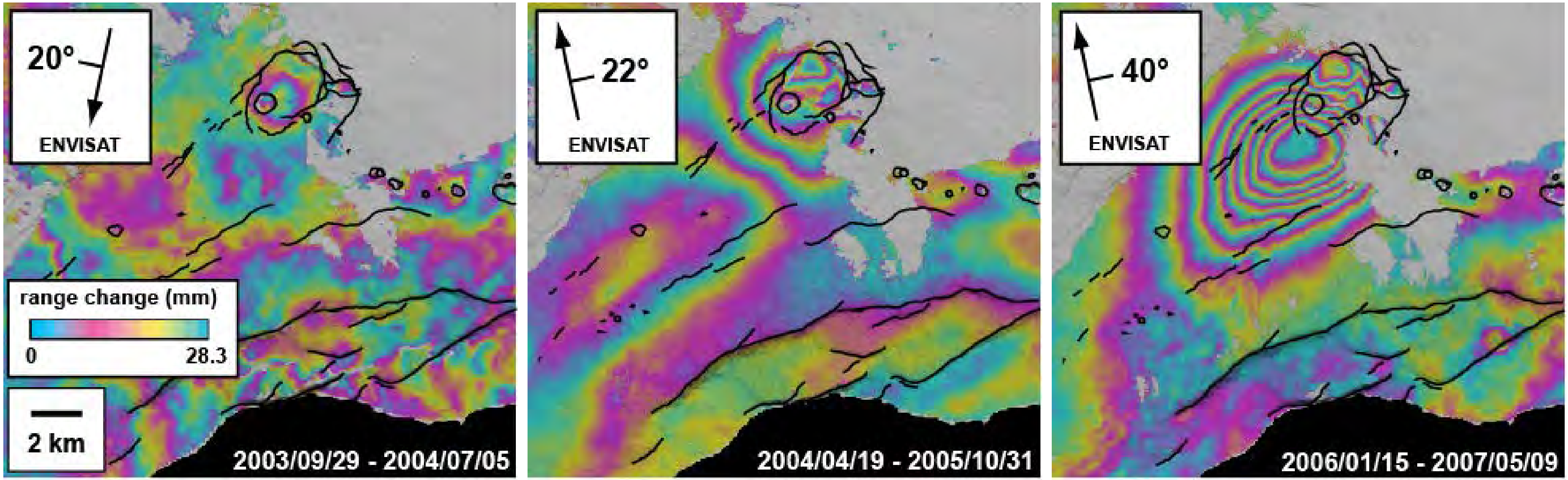


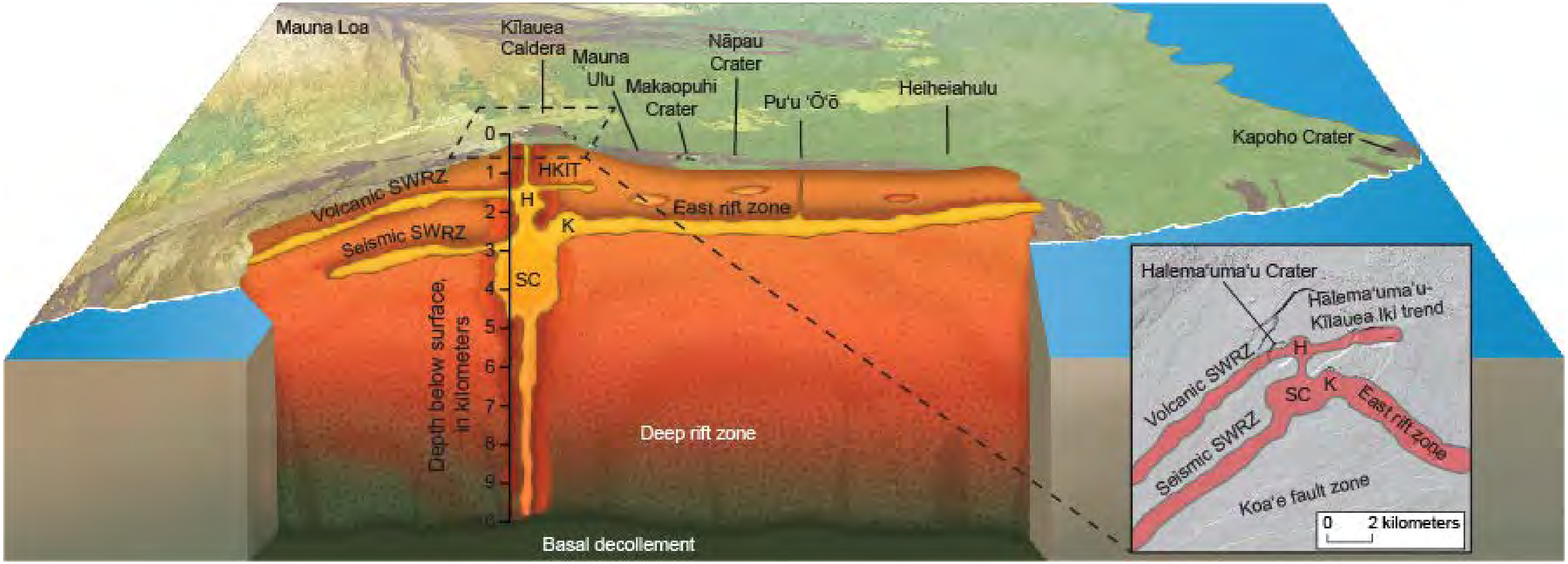
A simple volcanic system
2. Discharging the system
(a. eruptions)



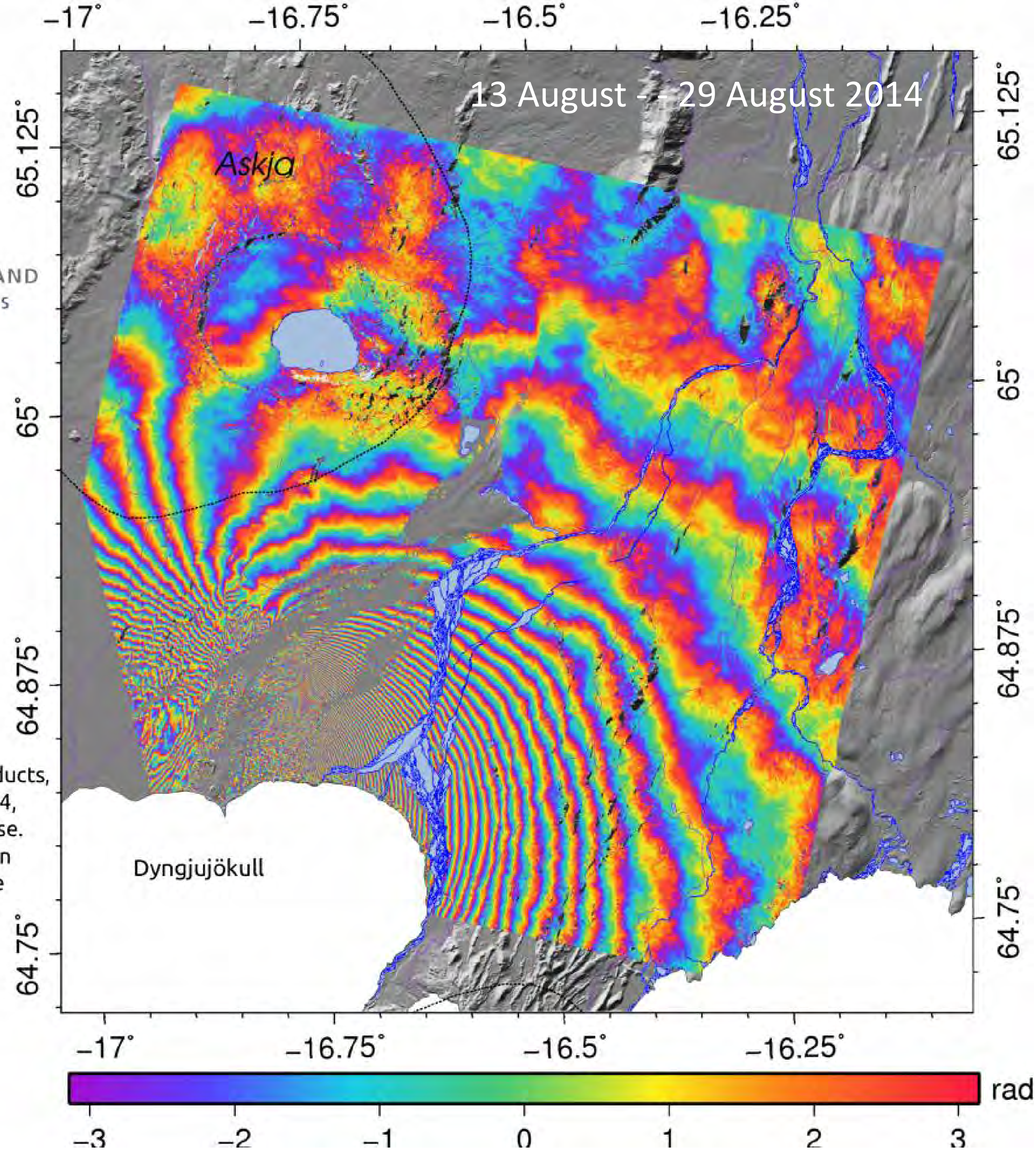
A simple volcanic system
2. Discharging the system
(b. intrusions)







USGS Courtesy Mike Poland, Hawaii Volcano Observatory

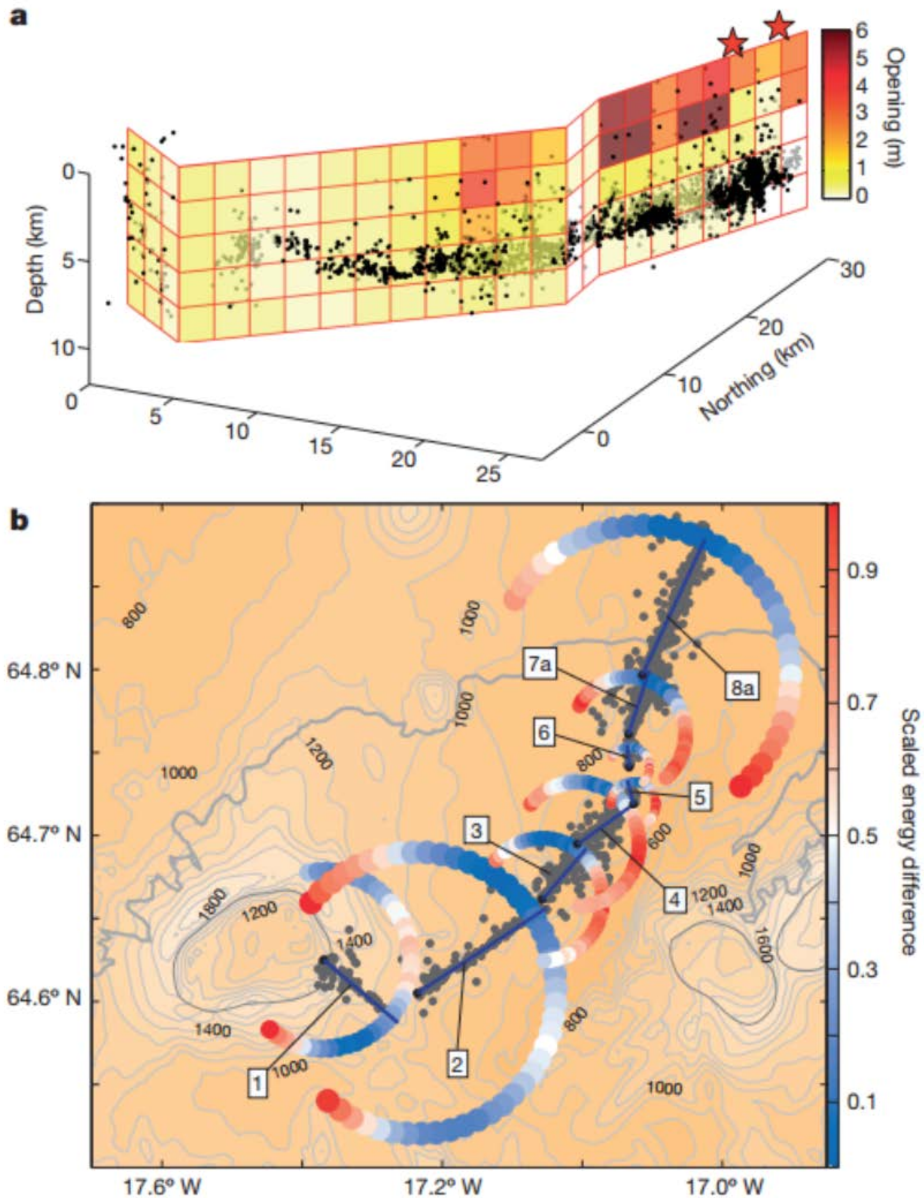


UNIVERSITY OF ICELAND
INSTITUTE OF EARTH SCIENCES

UNIVERSITY OF LEEDS

NordVulk

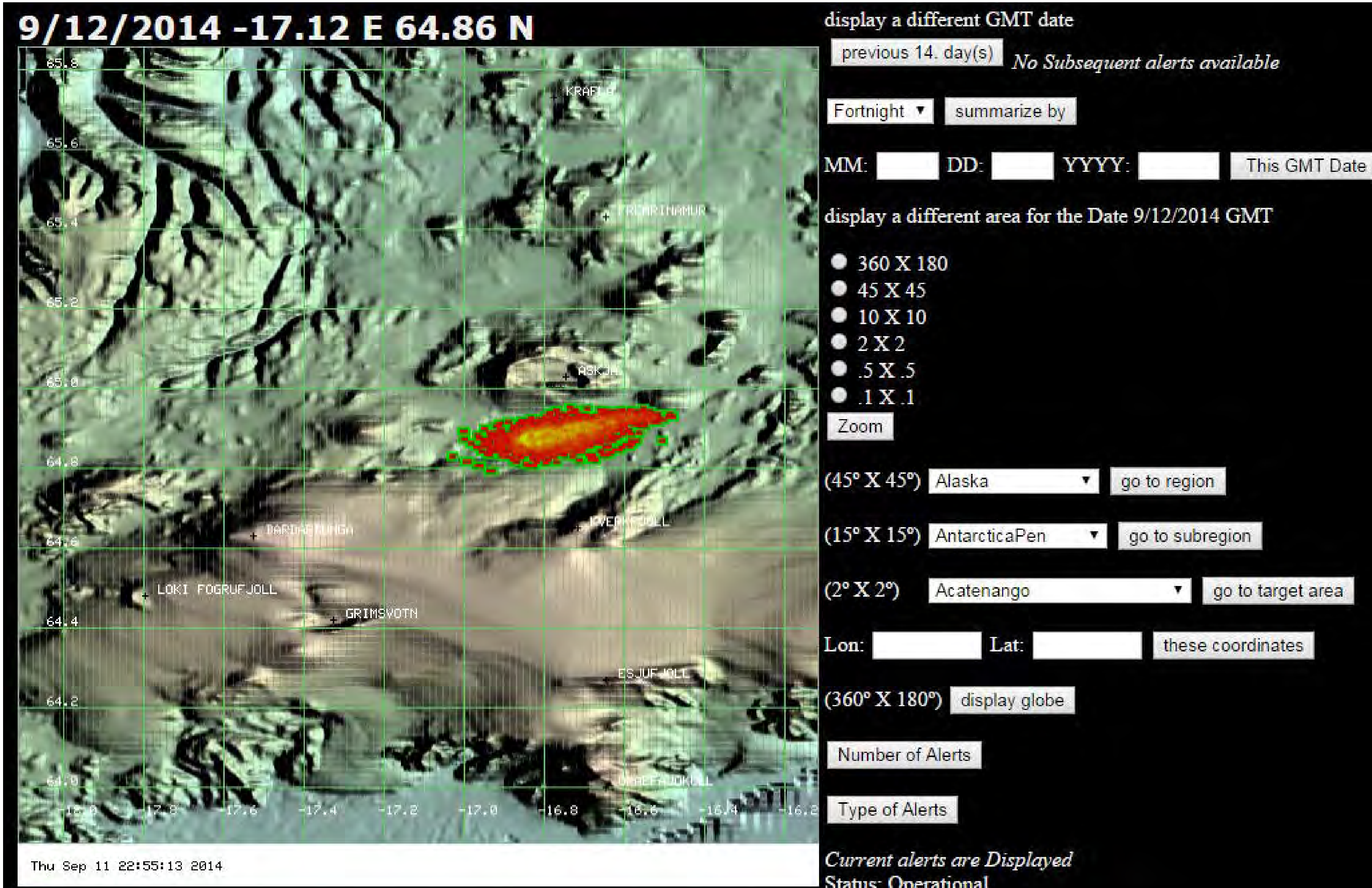
Processing carried out using CSK Products,
© ASI (Italian Space Agency) - 2014,
delivered under an ASI license to use.
COSMO-SkyMed images have been
provided in the framework of the
Geohazard Supersite Initiative



Sigmundsson, Hooper et al., Nature 2014

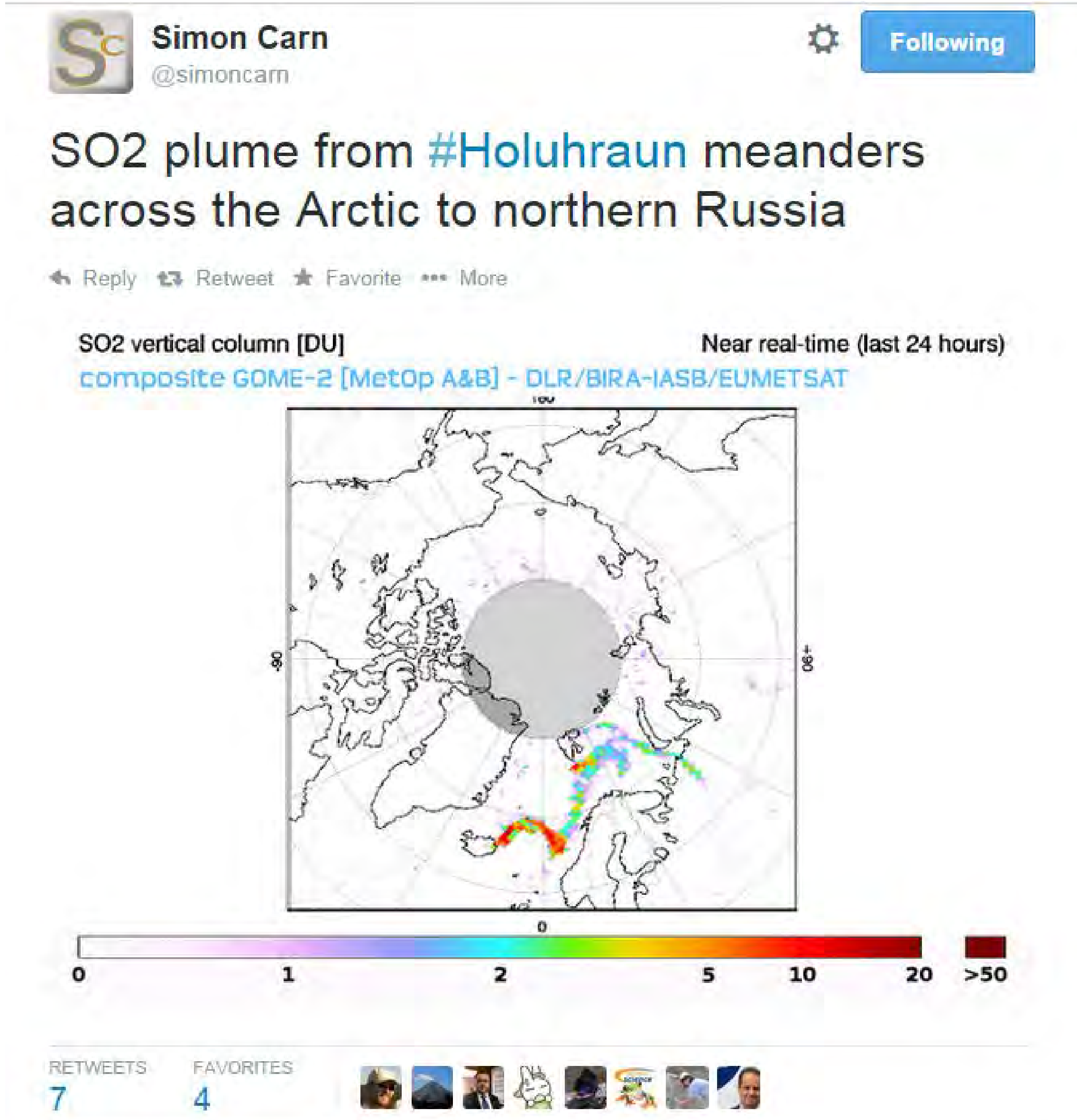
Q2 Has a volcano erupted

MODIS Thermal Hotspot Alerts



Method: Robert Wright et al., 2004

http://modis.higp.hawaii.edu/



From absorption spectra in the UV

IASI (Infrared):
e.g. Sears et al., JGR 2013

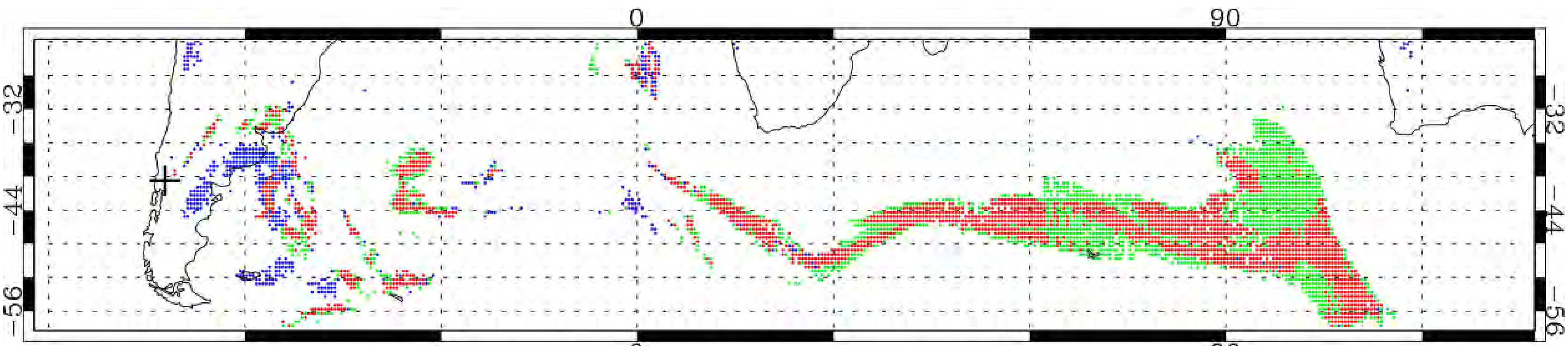


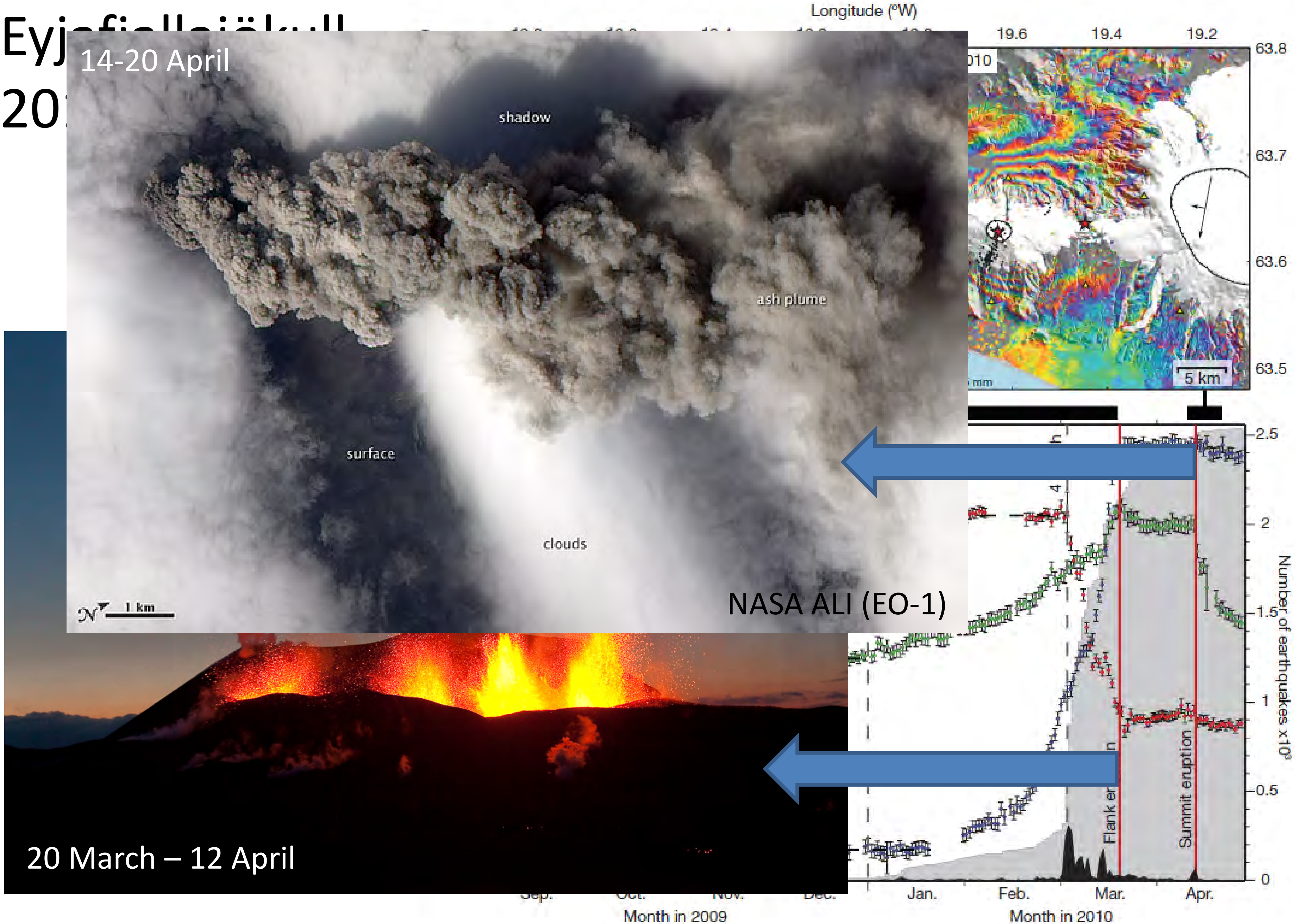
Figure 9. The location of ash and SO_2 from the Puyehue eruption for the morning of 9 June 2011 using the IASI SO_2 and ash flags. The black cross marks the location of the volcano. (red) Both ash and SO_2 are present; (green) Only SO_2 is present; (blue) Only ash is present.

Bardabunga lava from Landsat 8

Q3 How much has erupted?

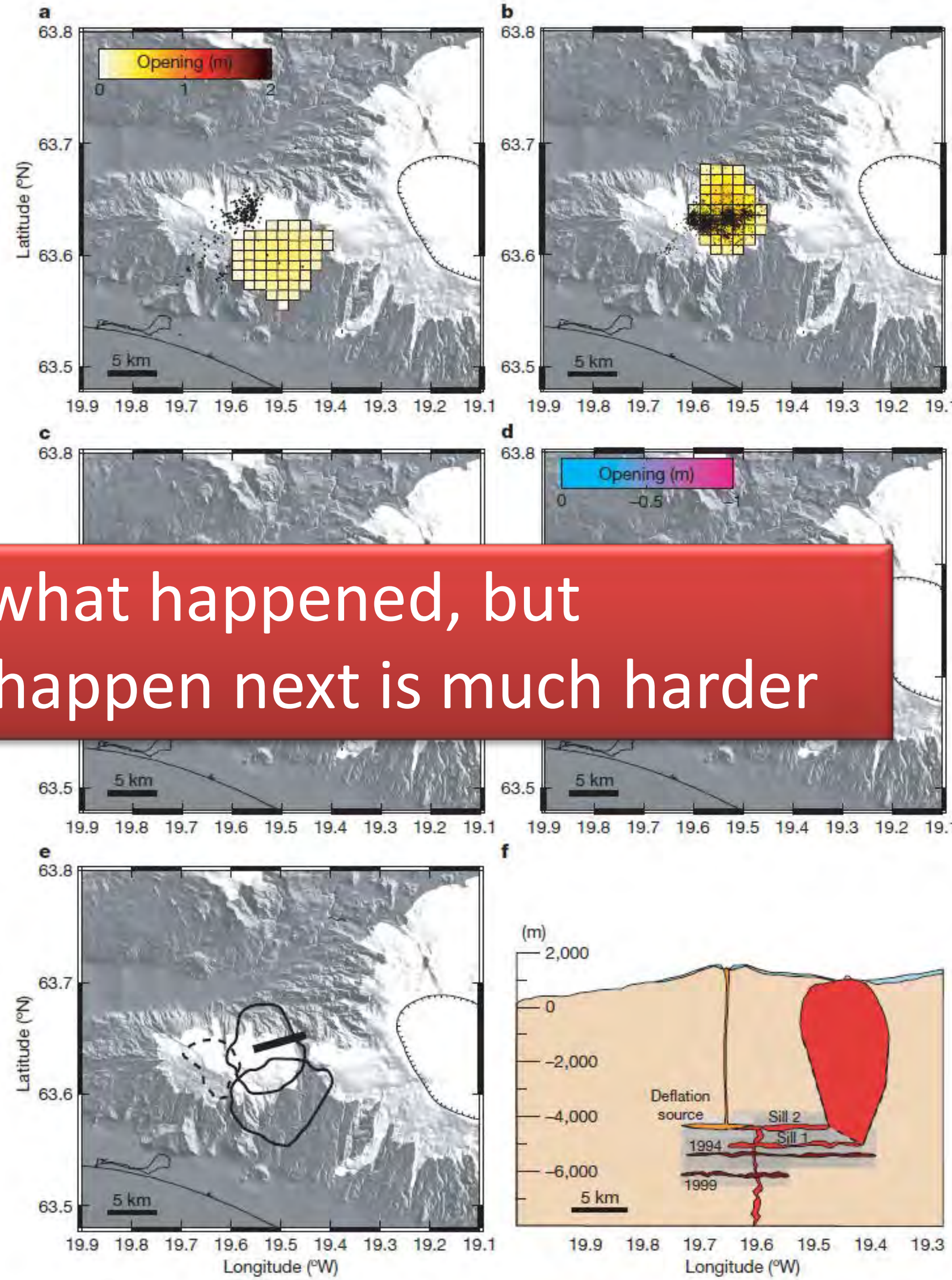
Q4 What will happen next?

Eyjafjallajökull 20



Sigmundsson et al., Nature 2010

Eyjafjallajökull 2010



We can understand what happened, but predicting what will happen next is much harder

Sigmundsson et al., Nature 2010

Geological Society, London, Special Publications published online March 20, 2013 as doi: 10.1144/SP380.4
VOLCANO DEFORMATION AND FORECASTING

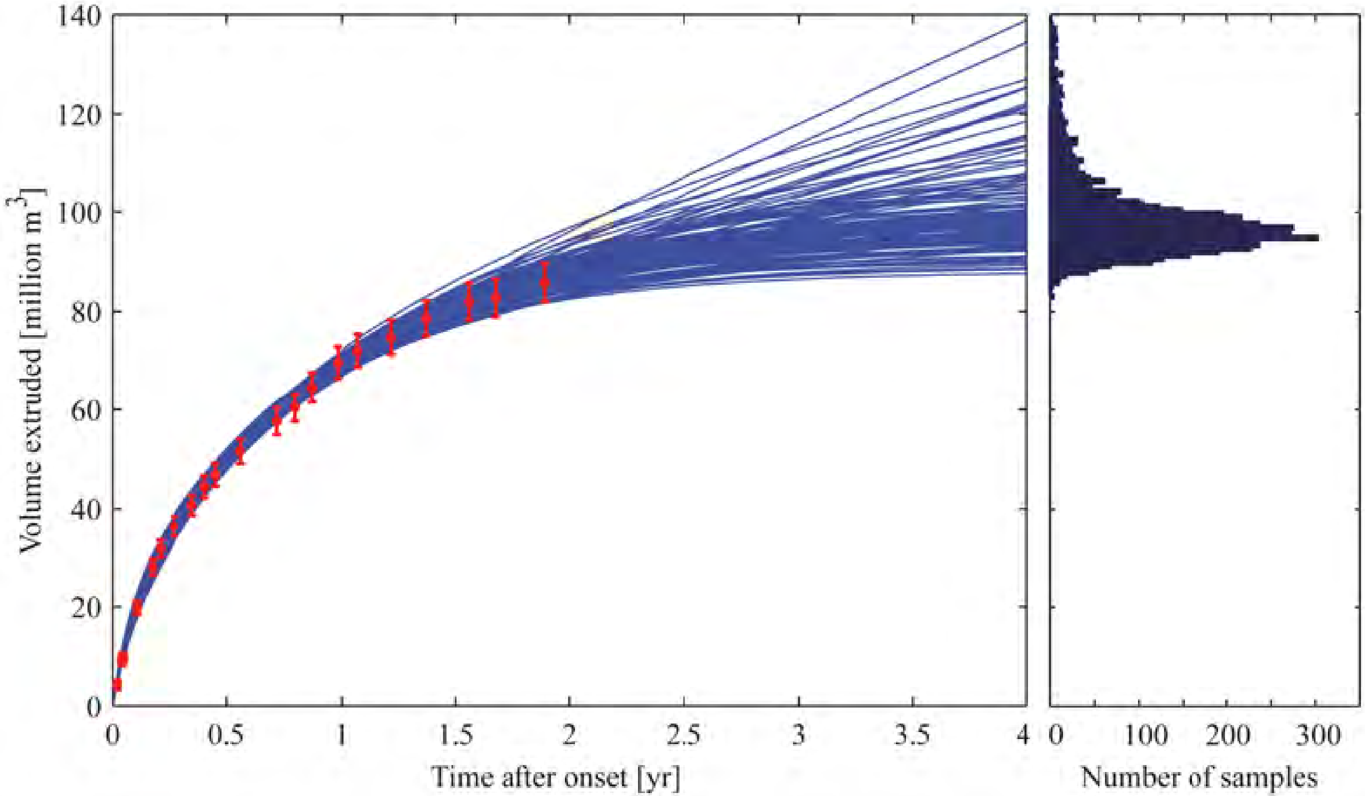


Fig. 15. Example of MCMC forecast using data from Mount St Helens for 2 years following eruption onset. Extruded volume is shown with 1σ error bars (red in online version). MCMC procedure yields a large set of model estimates consistent with the data (GPS data not shown). The model parameters were then used to simulate the erupted volume as a function of time (curves; 150 trajectories are shown). Right panel shows total erupted volume at the end of 4 years (5000 samples).

Paul Segall, Stanford

Tim Wright @timwright_leeds · Jan 29
Great session on #Holuhraun from @Michelle_Parks1 and @GeoAndyHooper.
Andy's models predict eruption will end on 17 feb +/- 2 days.

RETWEETS 15 FAVORITES 4

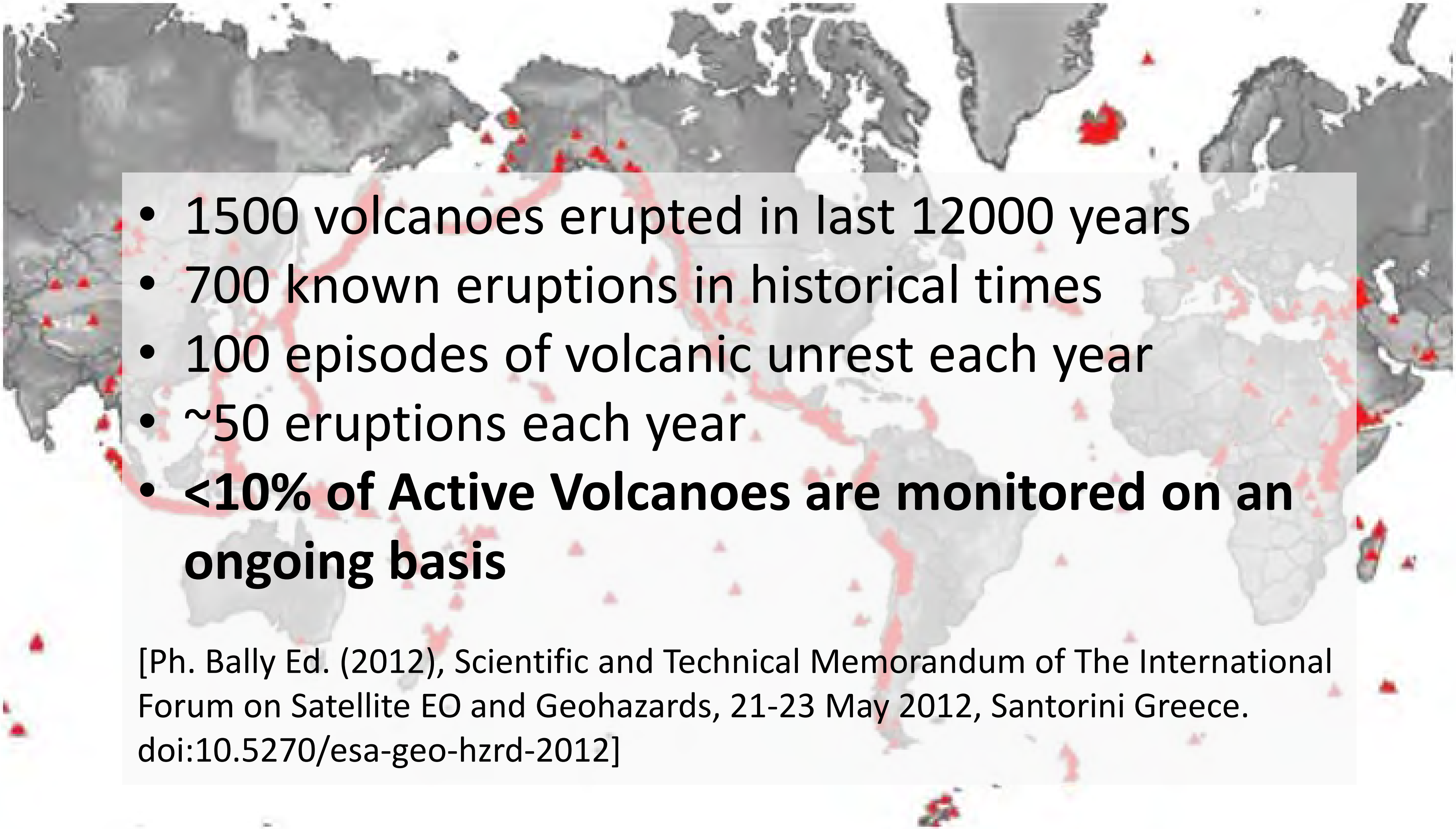
12:18 PM - 29 Jan 2015 · Details

Gymknickers @Gymknickers · Feb 6
@volcan01010 @timwright_leeds @Michelle_Parks1 @GeoAndyHooper Just what I didn't want to hear. Booked return trip mid March :(

John A Stevenson @volcan01010 · Feb 6
@Gymknickers @timwright_leeds @Michelle_Parks1 @GeoAndyHooper
Icelanders estimate 4-15 months more. en.vedur.is/media/jar/Fact... What's different?

Actual eruption end date: 27 February 2015

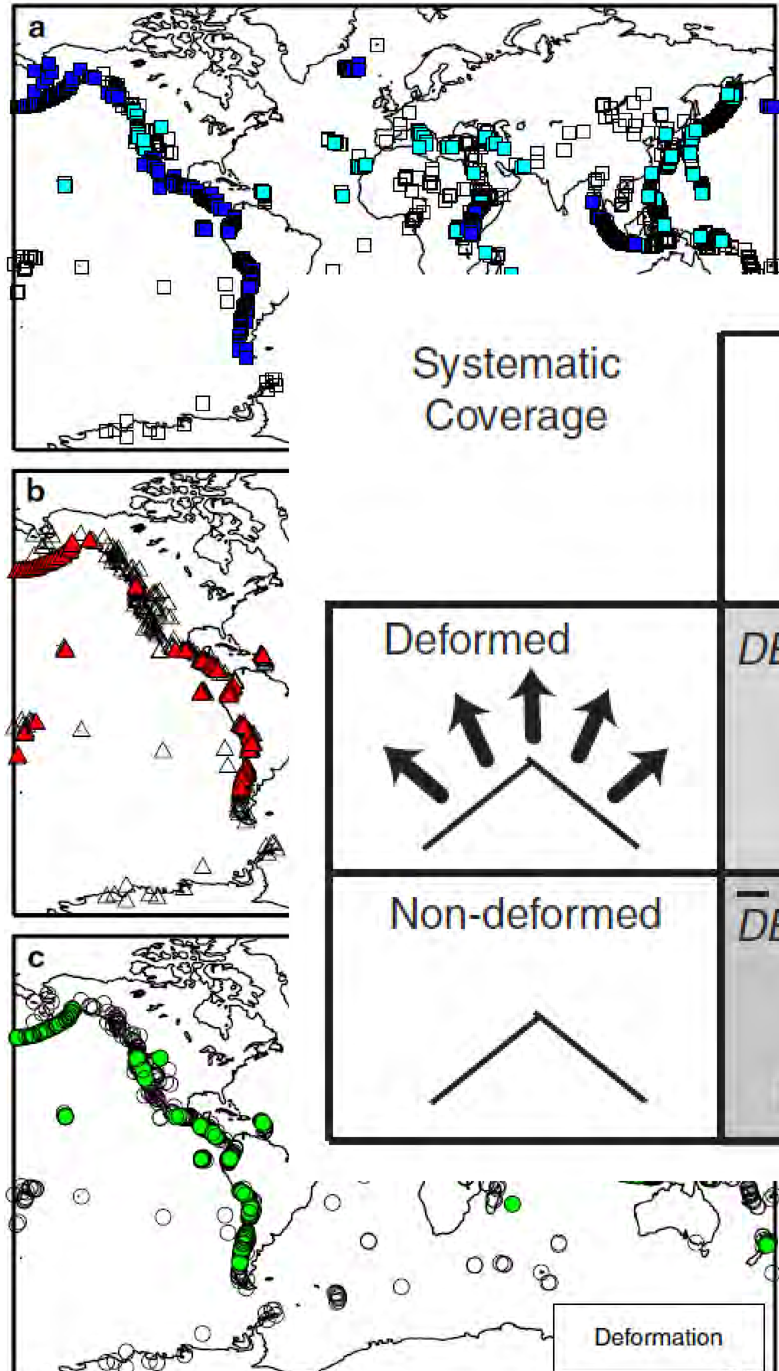
Q5 What is the probability of a volcano erupting?

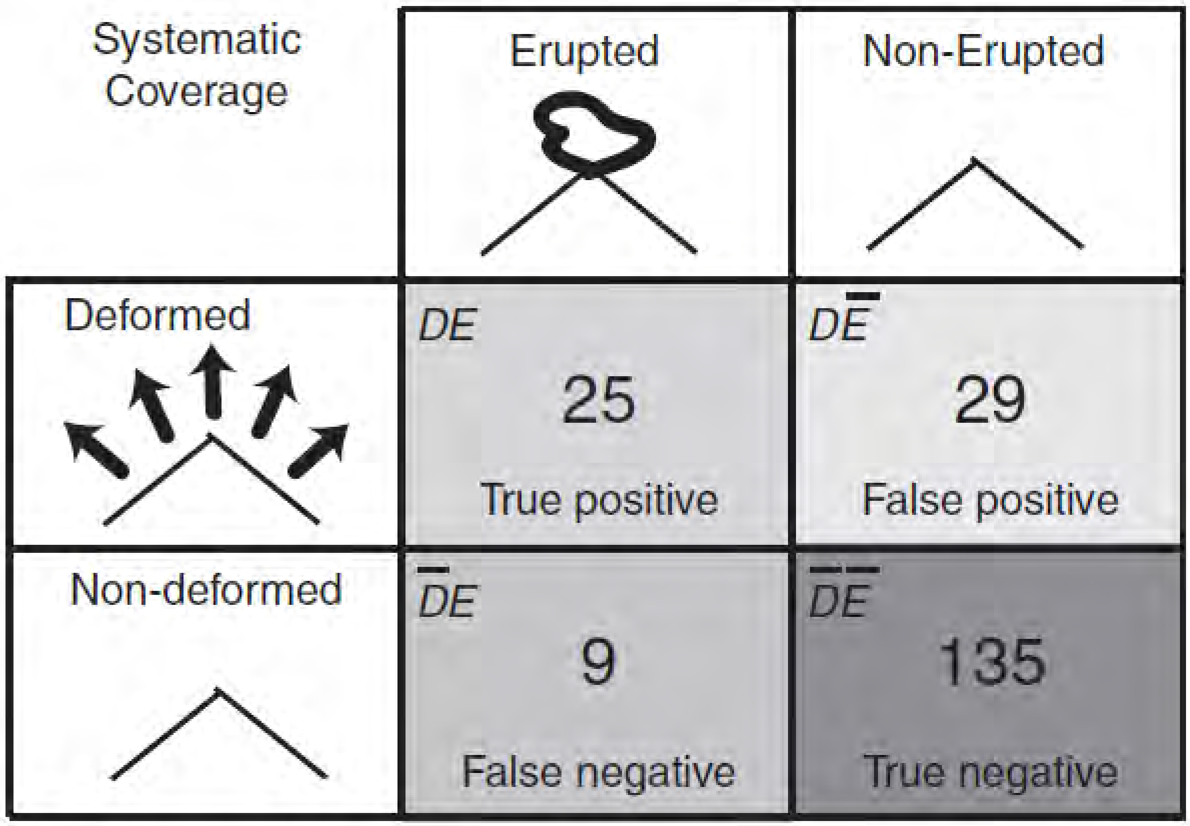


- 1500 volcanoes erupted in last 12000 years
- 700 known eruptions in historical times
- 100 episodes of volcanic unrest each year
- ~50 eruptions each year
- **<10% of Active Volcanoes are monitored on an ongoing basis**

[Ph. Bally Ed. (2012), Scientific and Technical Memorandum of The International Forum on Satellite EO and Geohazards, 21-23 May 2012, Santorini Greece. doi:10.5270/esa-geo-hzrd-2012]

Can systematic deformation observations help?





Biggs et al., Nature Communications 2014

Reminder of Take Home Messages

1.Earth observation is **the key tool** in understanding our hazardous planet.

2. EO tools need to be integrated into the standard kitbag of every geologist, volcanologist, seismologist…

3. We can only solve the big problems by integrating EO with data from different disciplines.

@timwright_leeds
@NERC_COMET