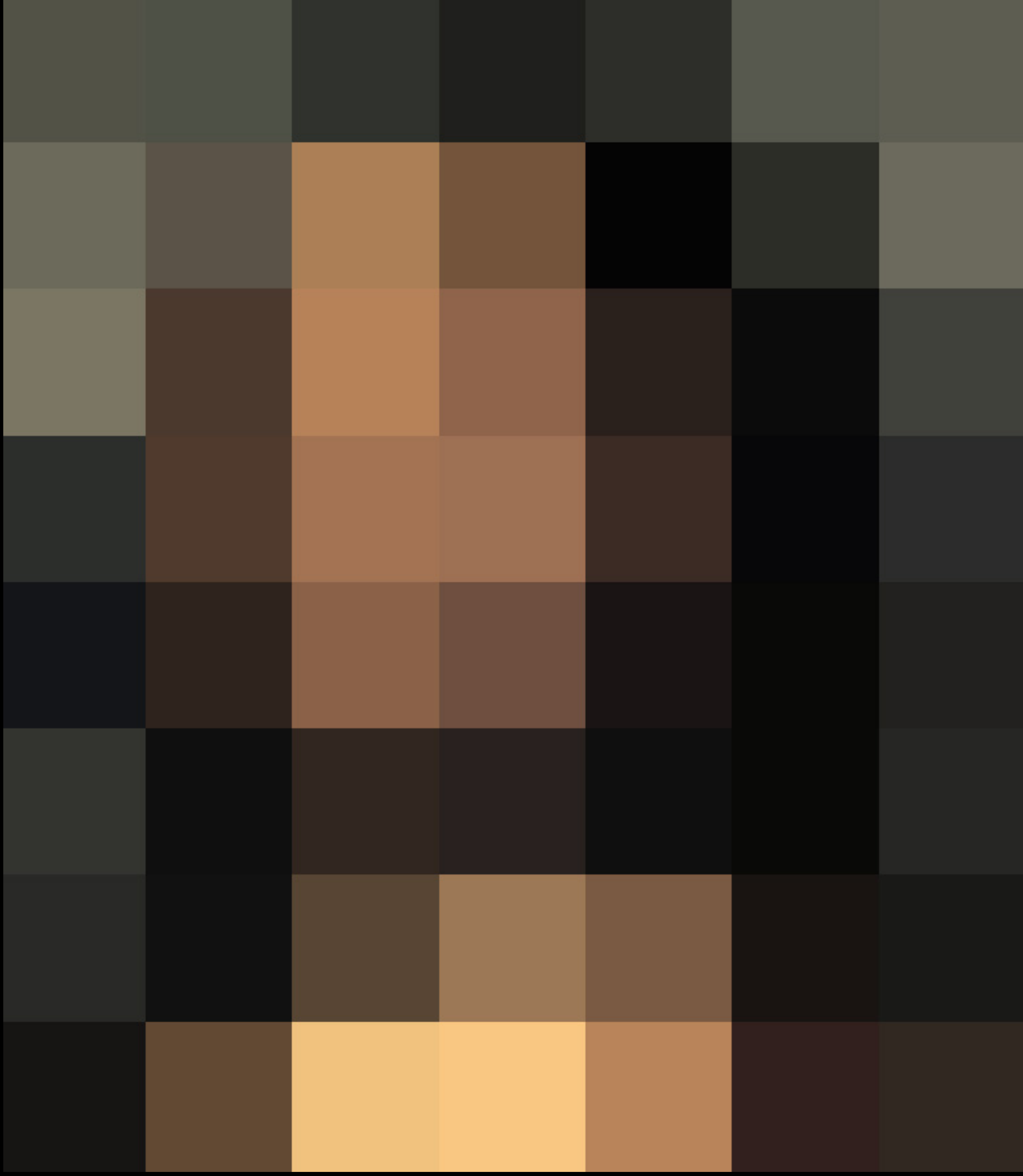
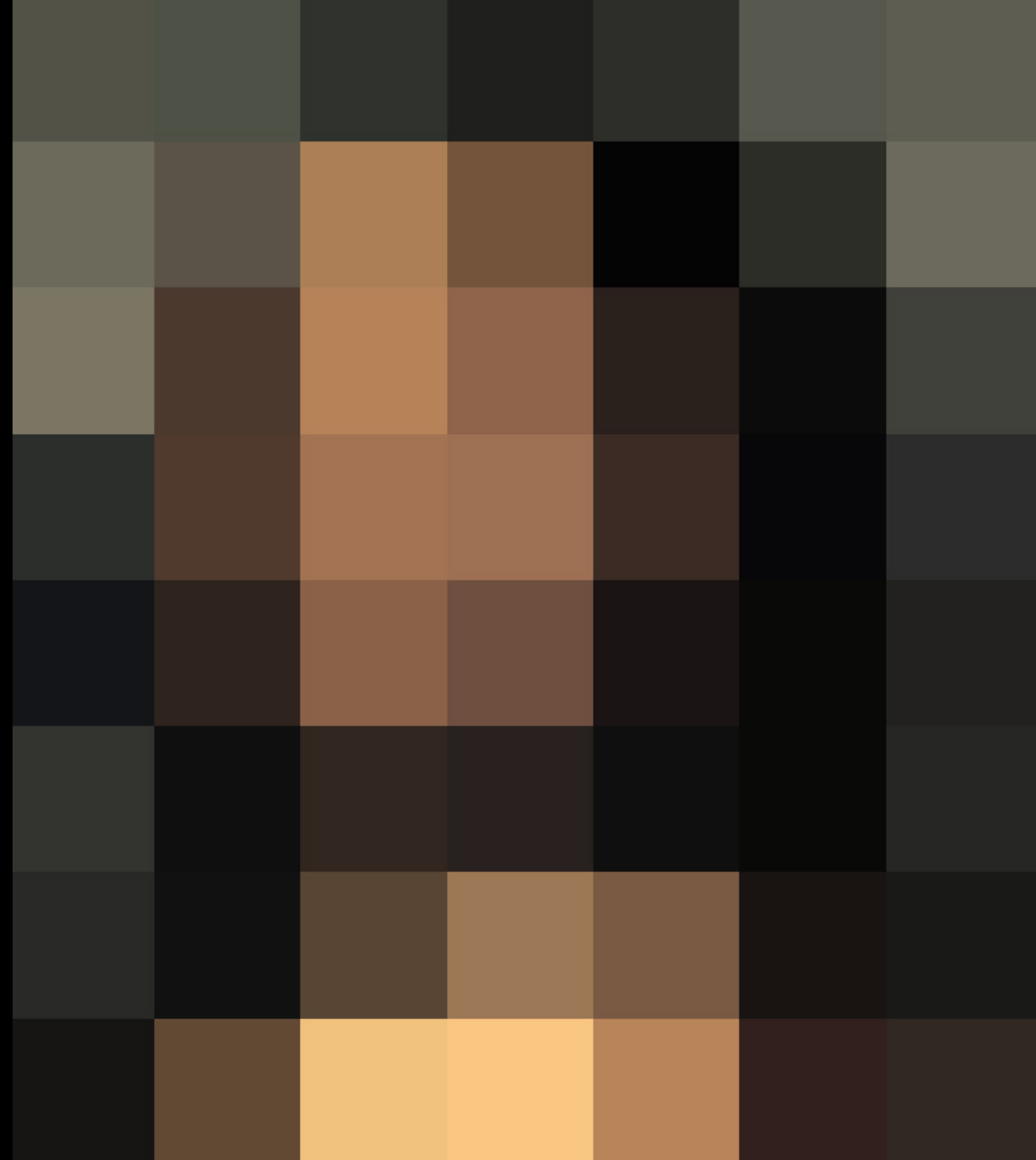


resolution:
(1.4 meter)
/
(7 pixels)

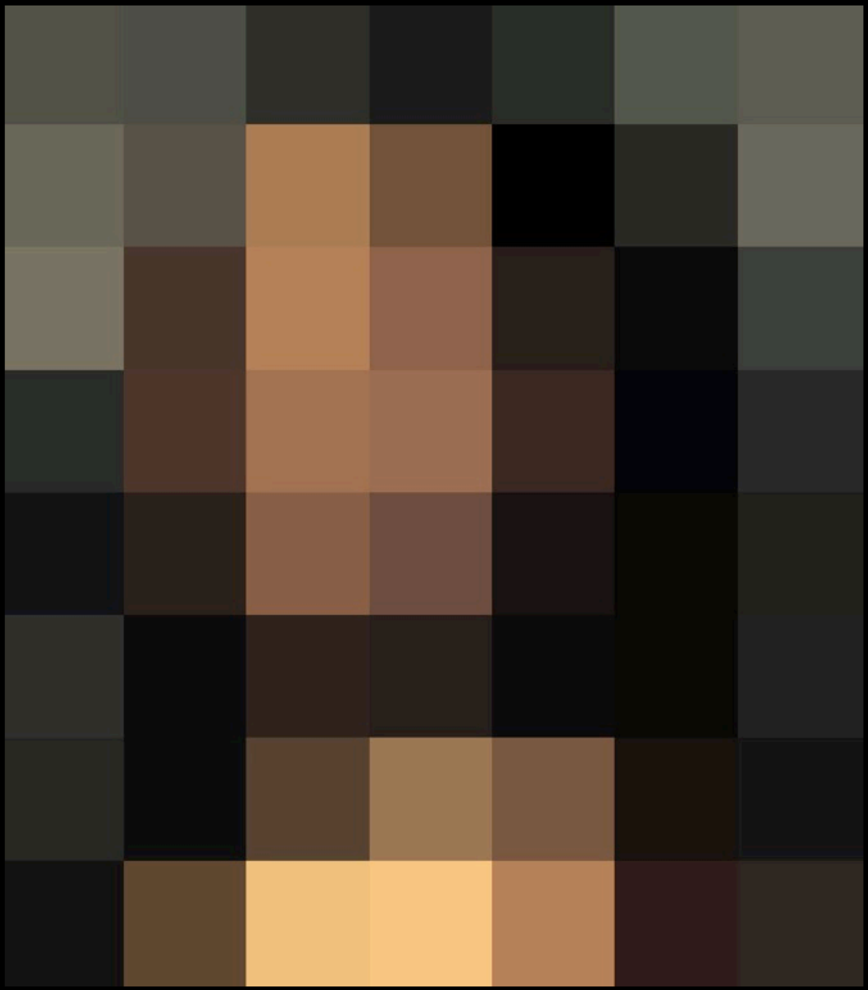
=

~ 0.2 m/pixel

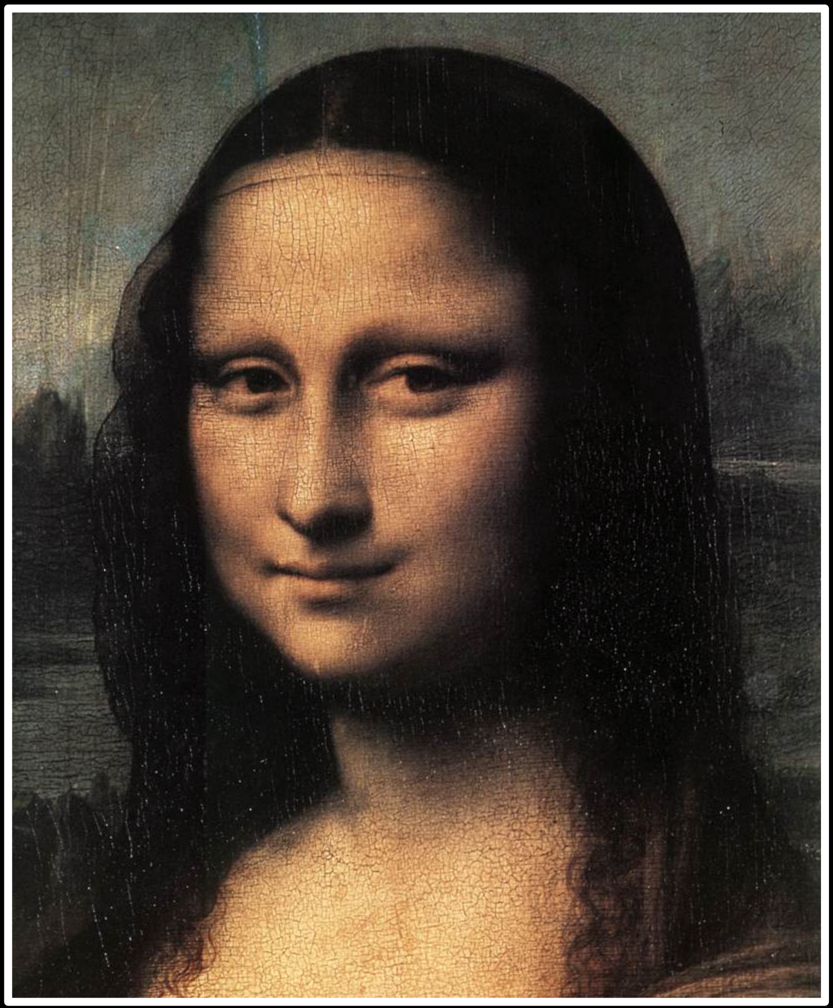


resolution

~ 0.2 m/pixel



~ 0.002 m/pixel

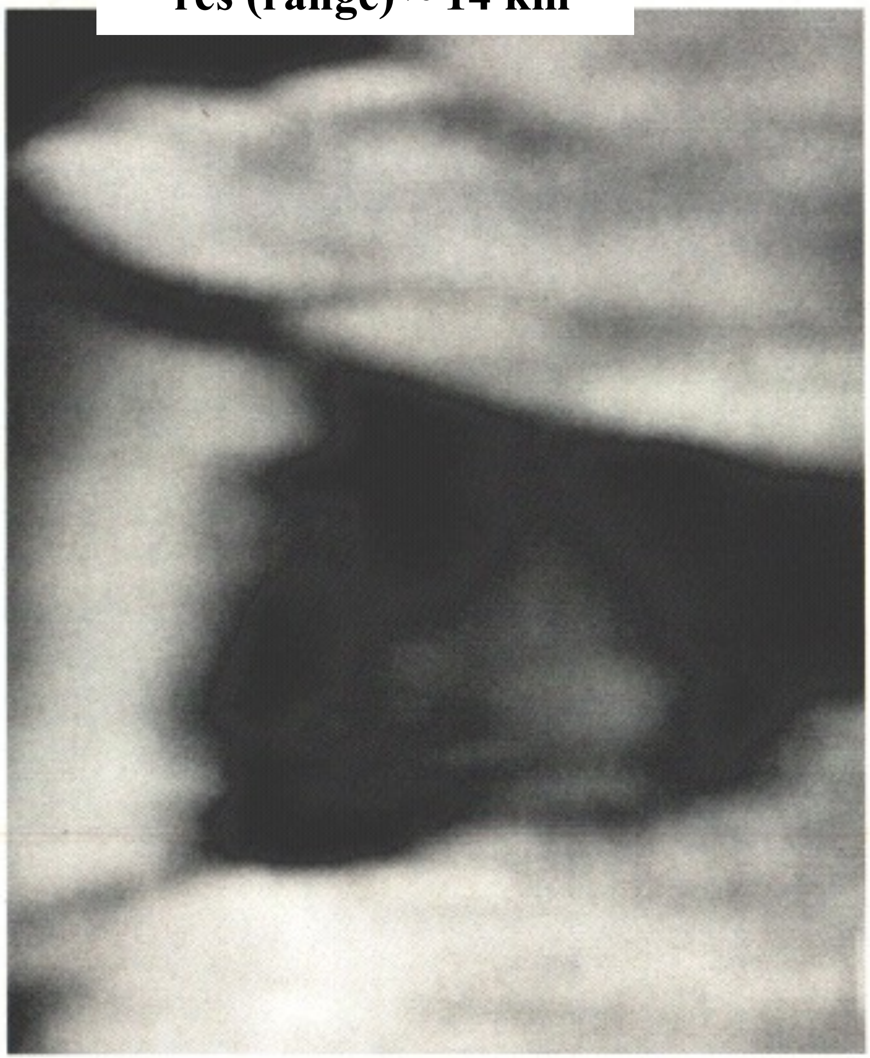


Synthetic Aperture Radar (SAR) focussing

Natural

res (azimuth) ~ 5 km

res (range) ~ 14 km

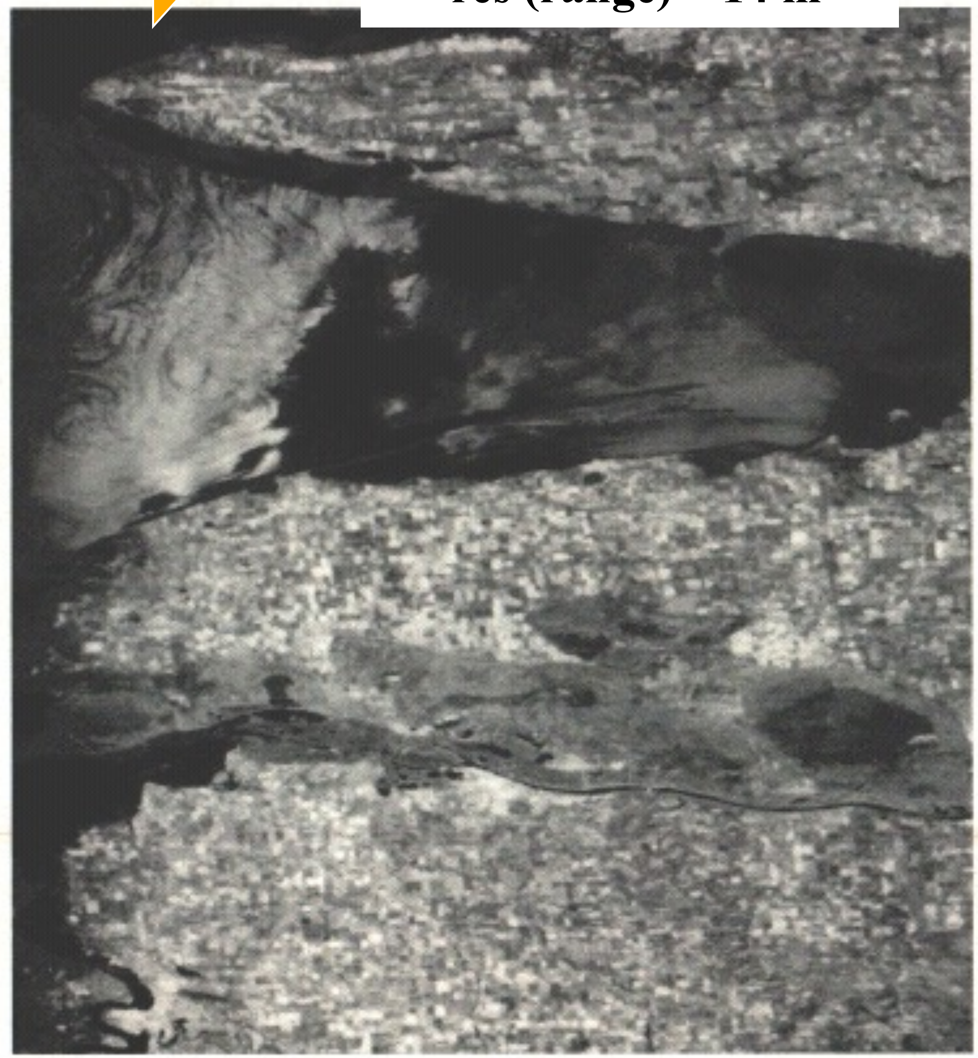


1000 X

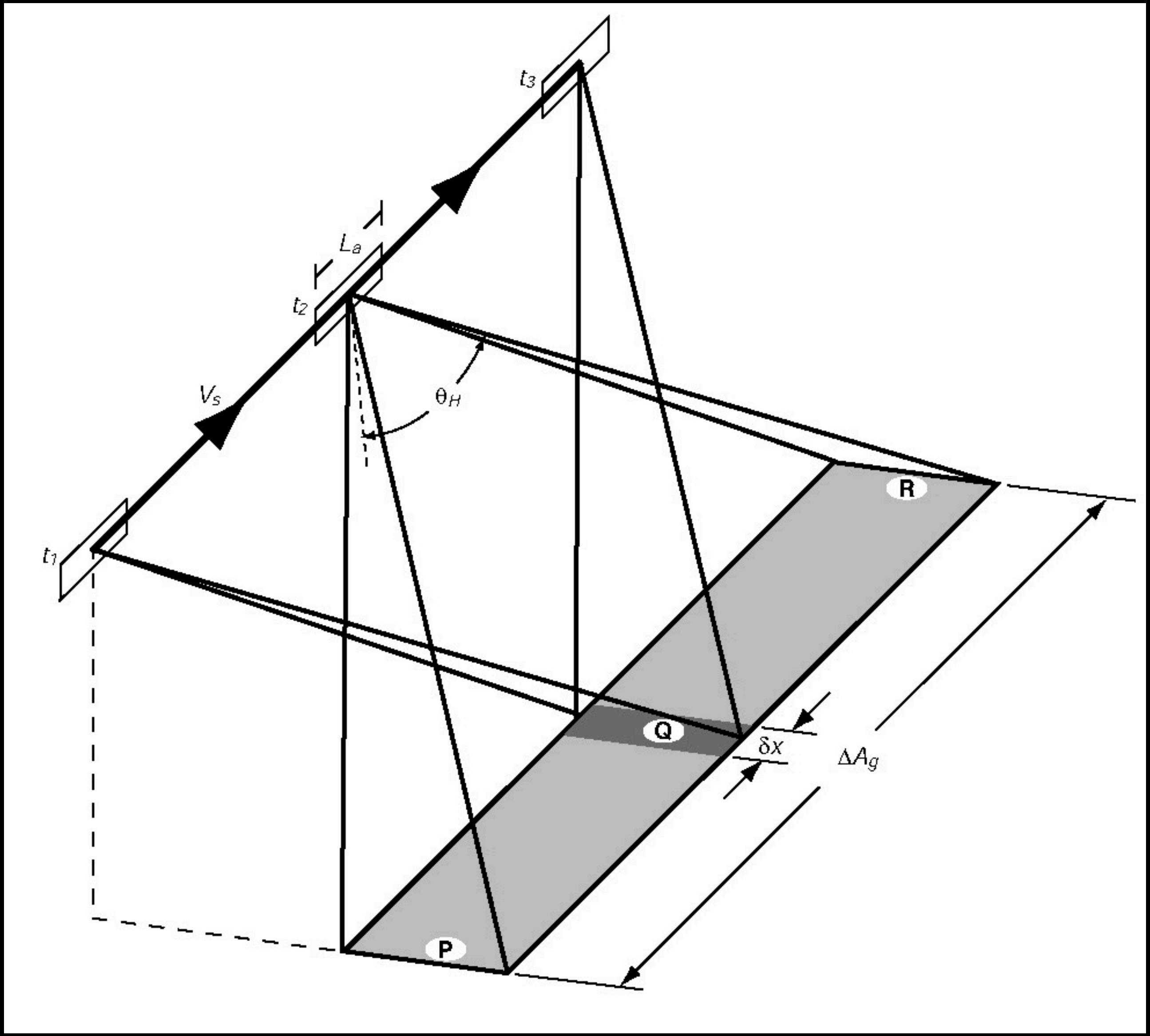
Focussed

res (azimuth) ~ 5 m

res (range) ~ 14 m



Synthetic Aperture = a bigger (virtual) antenna ➔ finer resolution



Funning, [2005]

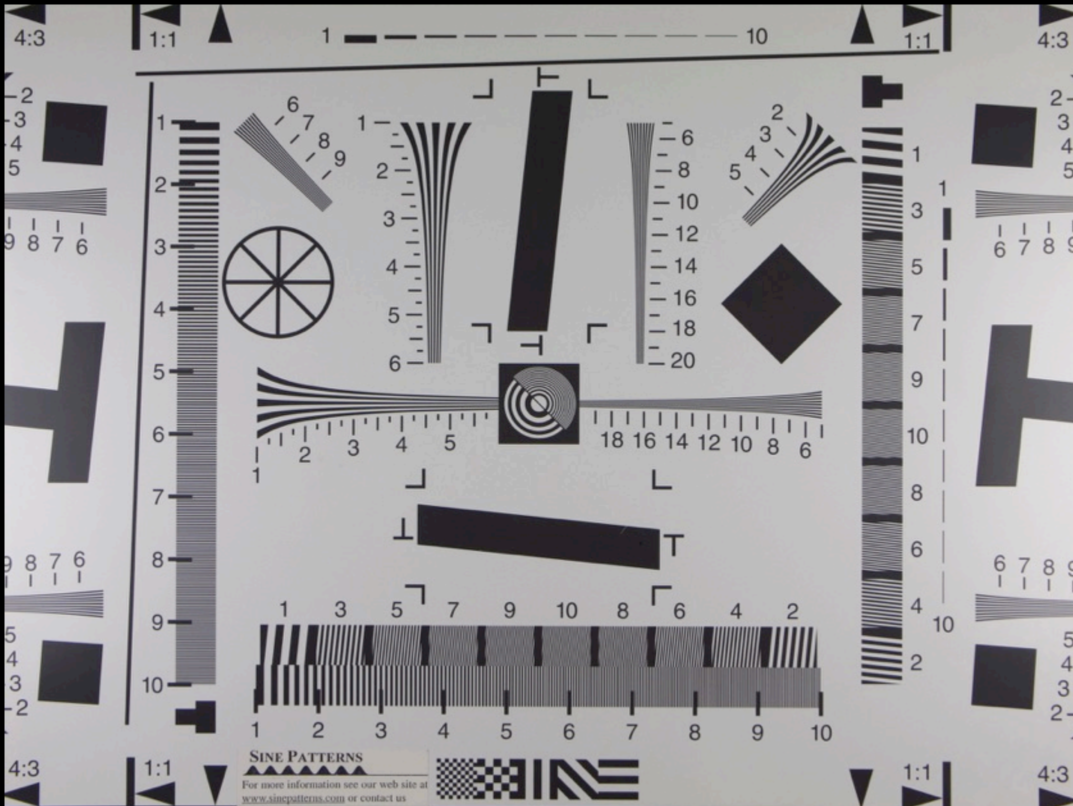
resolution

(spatial) resolution: width (in meters) of smallest object that a sensor can distinguish

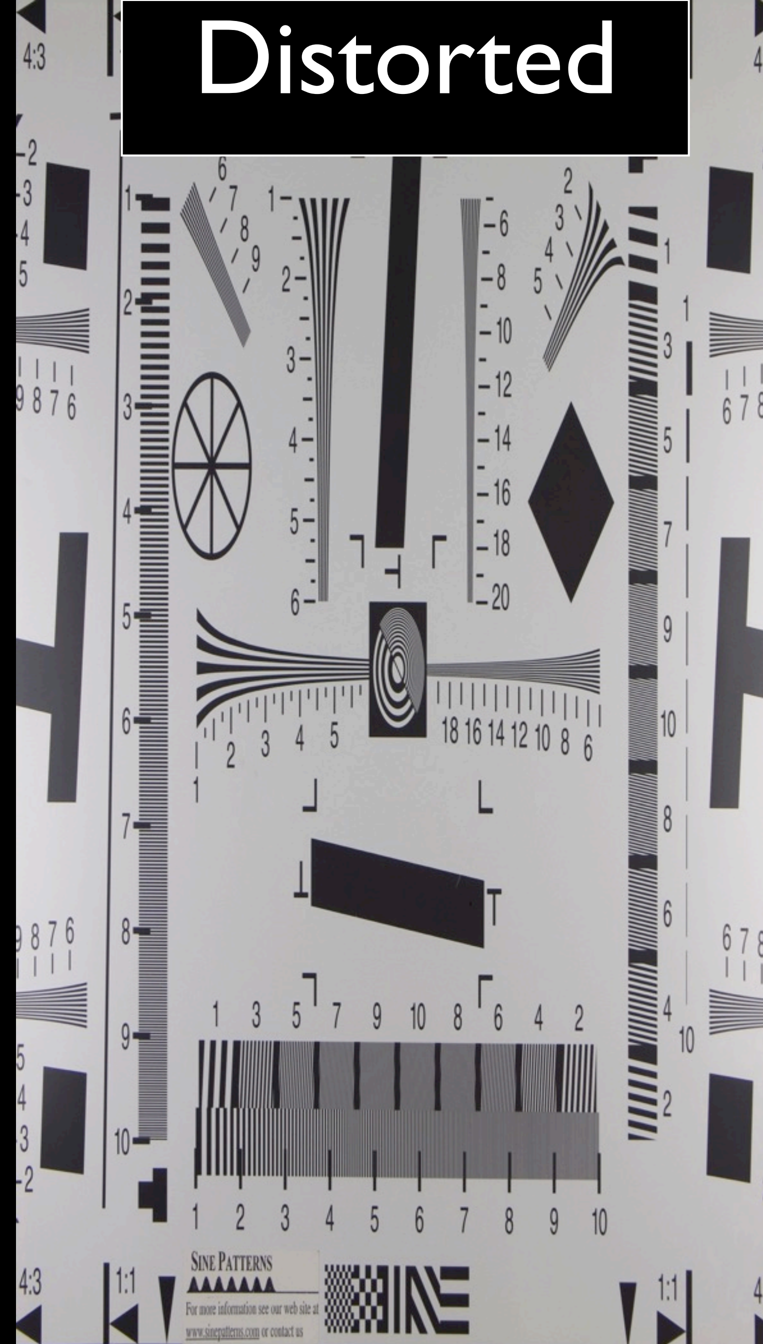
(image) resolution: "Basically, resolution quantifies how close lines can be to each other and still be visibly resolved." http://en.wikipedia.org/wiki/Image_resolution

"fine" versus "coarse" resolution

Correct

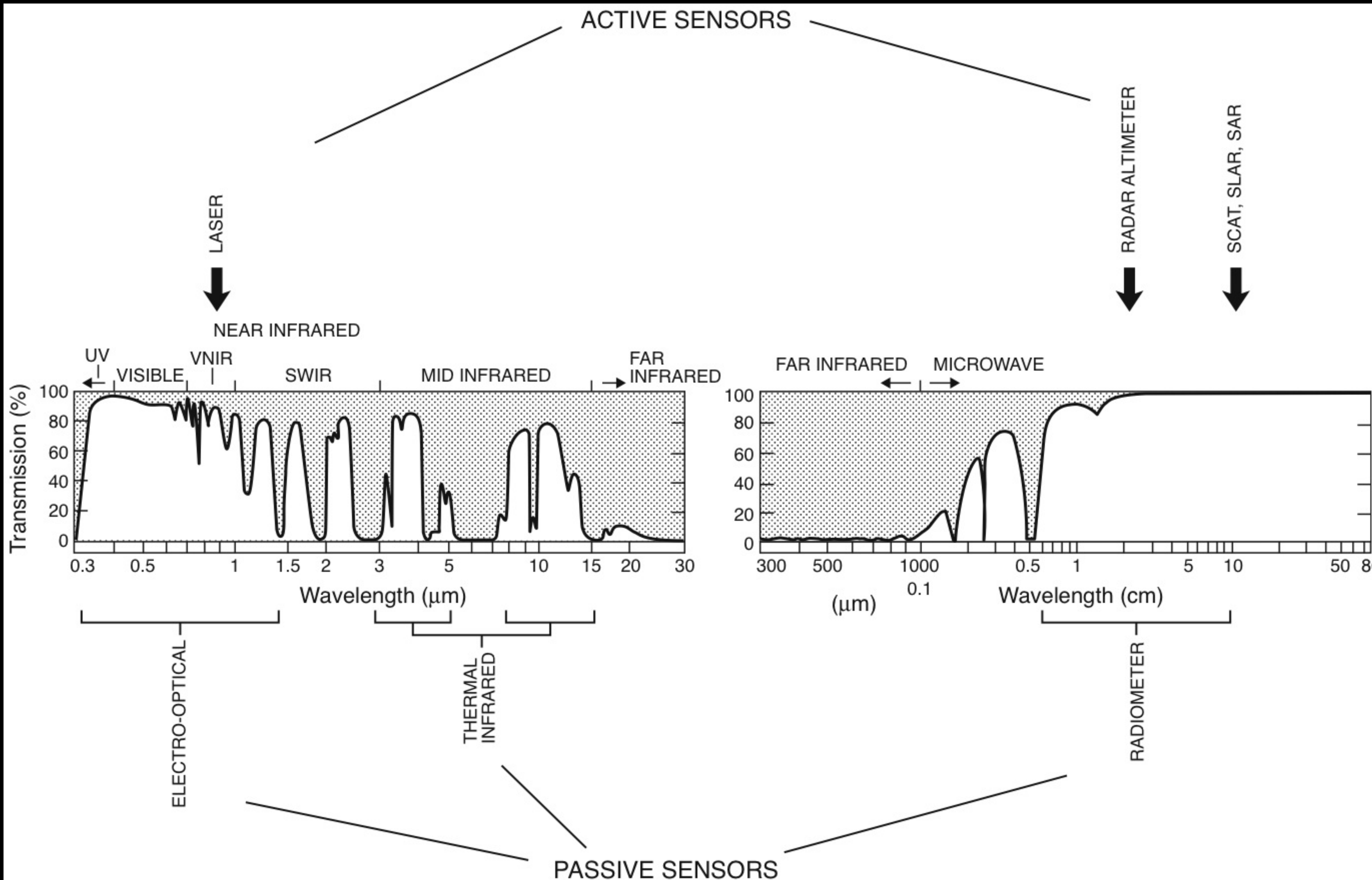


Distorted



https://www.appliedimage.com/products/sine-patterns-and-square-wave-targets

passive and active remote sensing – optical and microwave



RADAR = RAdio Detection And Ranging

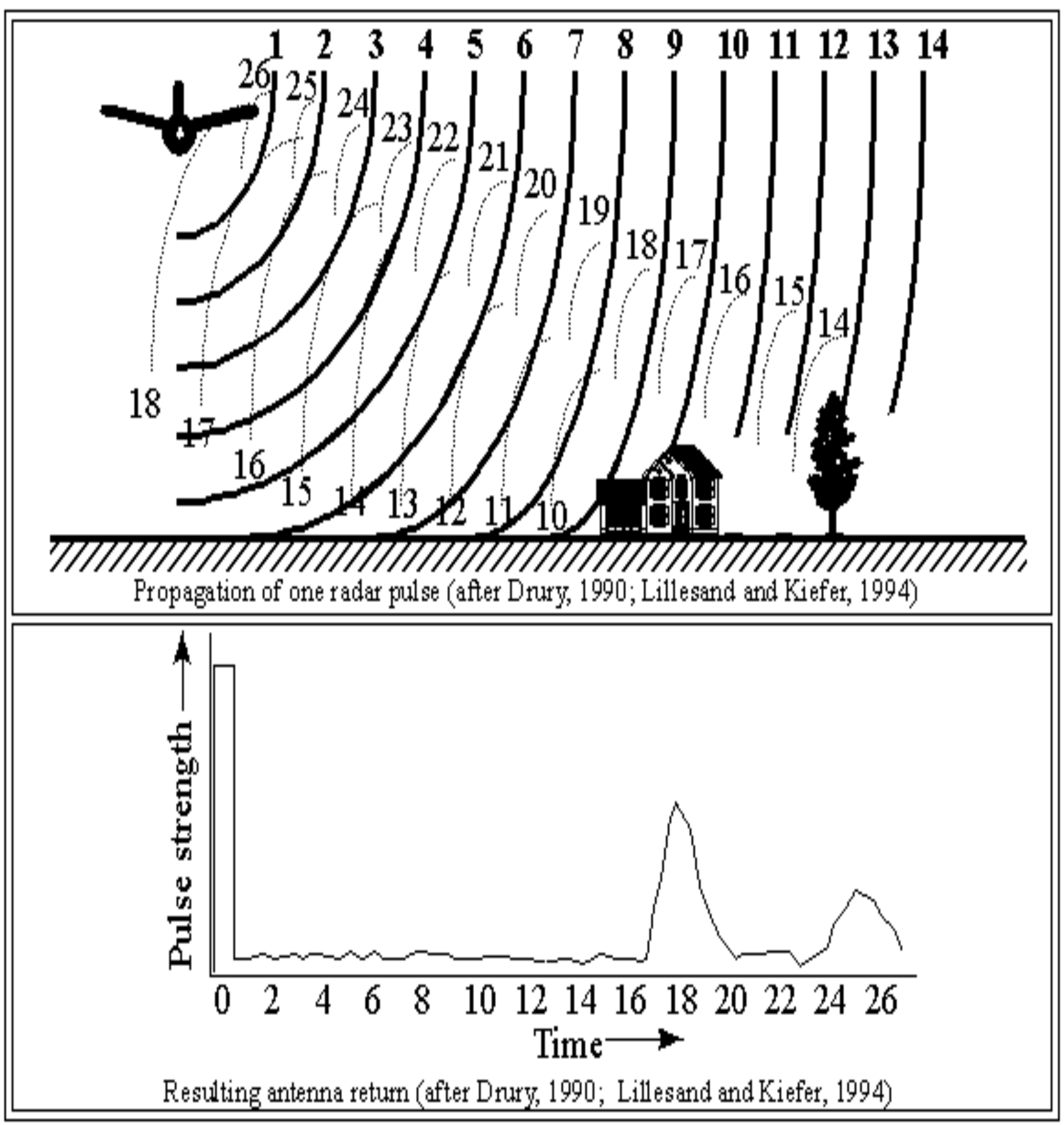
Active sensor

All weather

Night or day

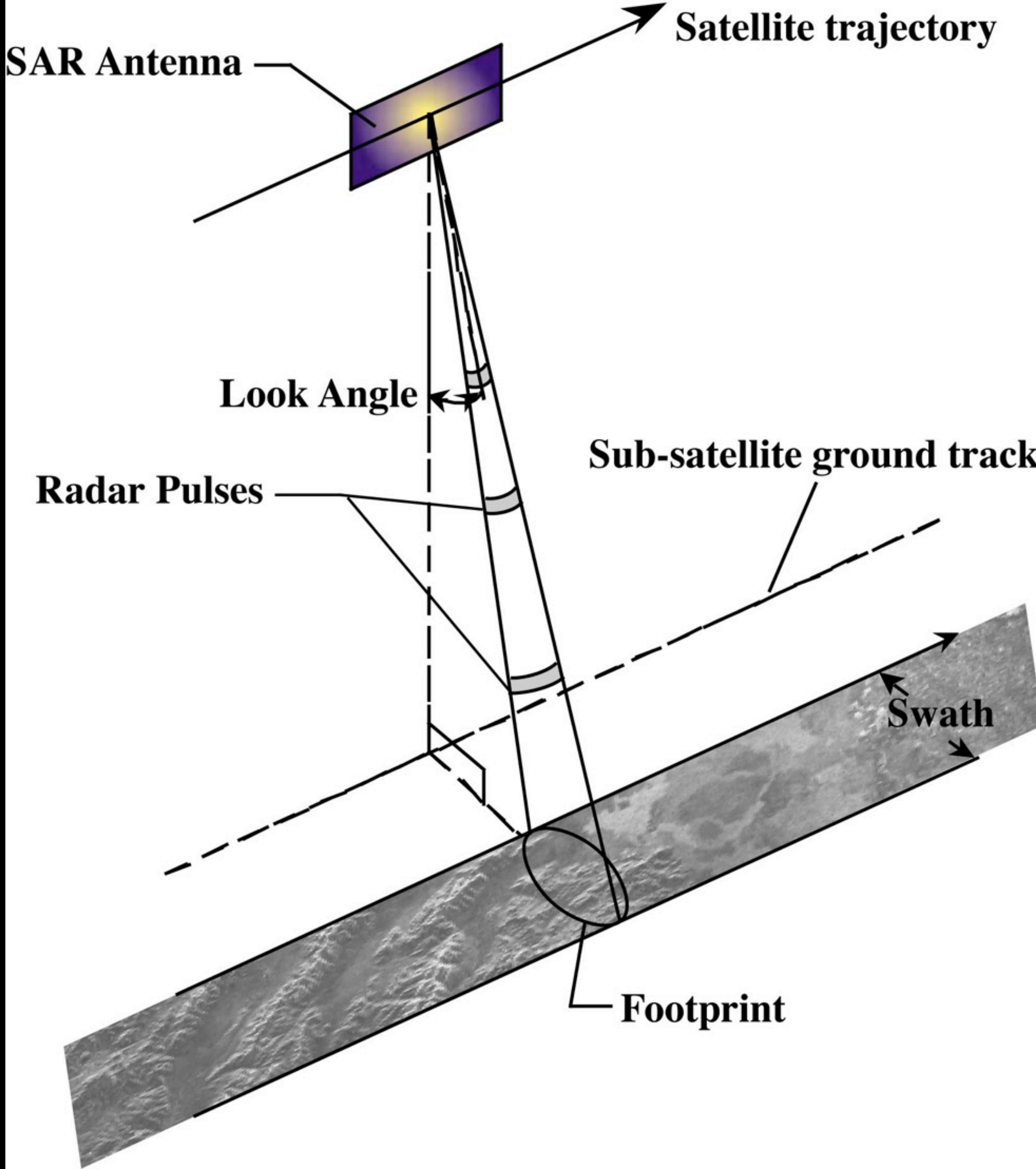
Like sonar:

first echo is from nearest object



Propagation of one radar pulse (after Drury, 1990; Lillesand and Kiefer, 1994)

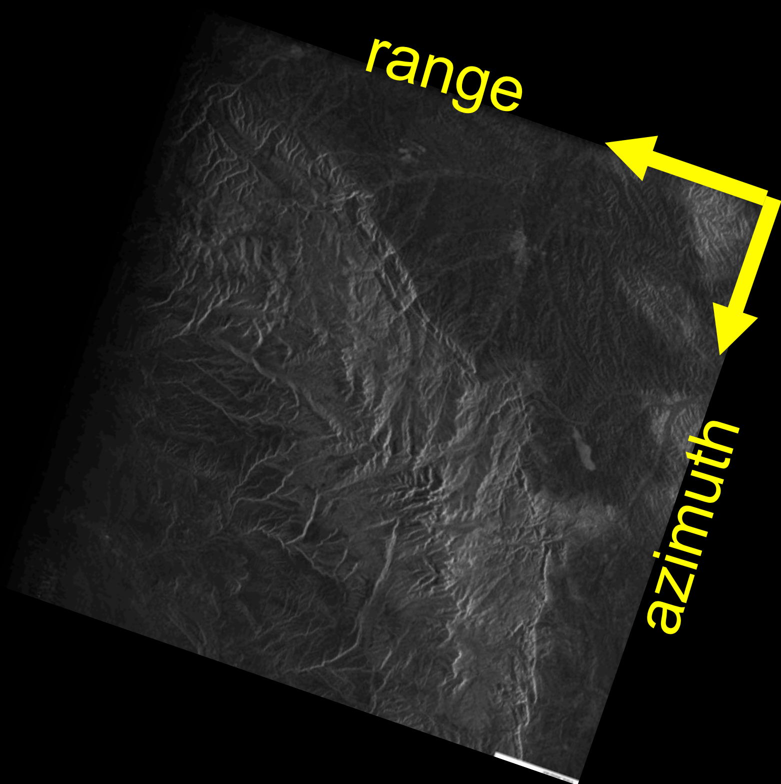
Resulting antenna return (after Drury, 1990; Lillesand and Kiefer, 1994)



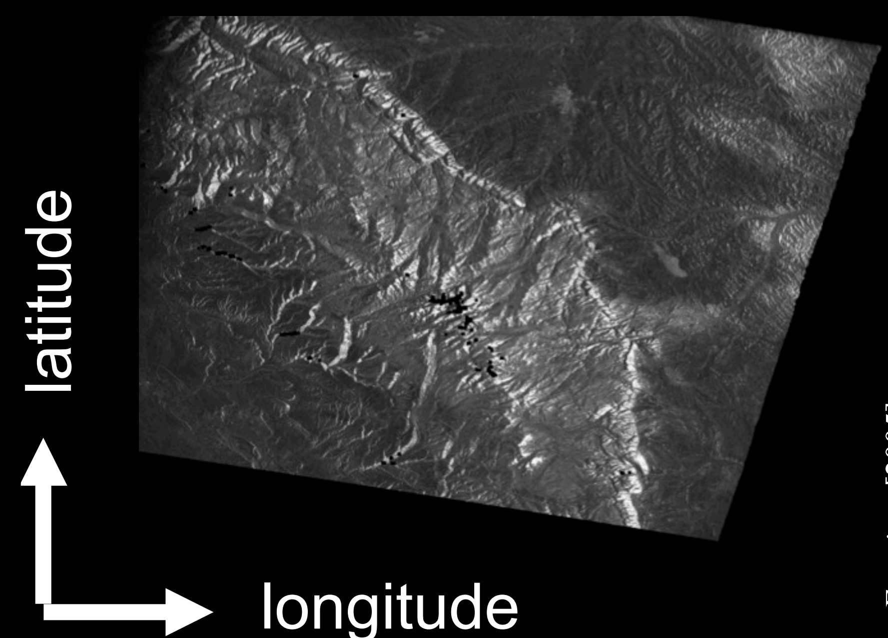
Satellite trajectory
SAR Antenna
Look Angle
Sub-satellite ground track
Radar Pulses
Swath
Footprint

geometric coordinates

radar



geographic



Funning. [2005]

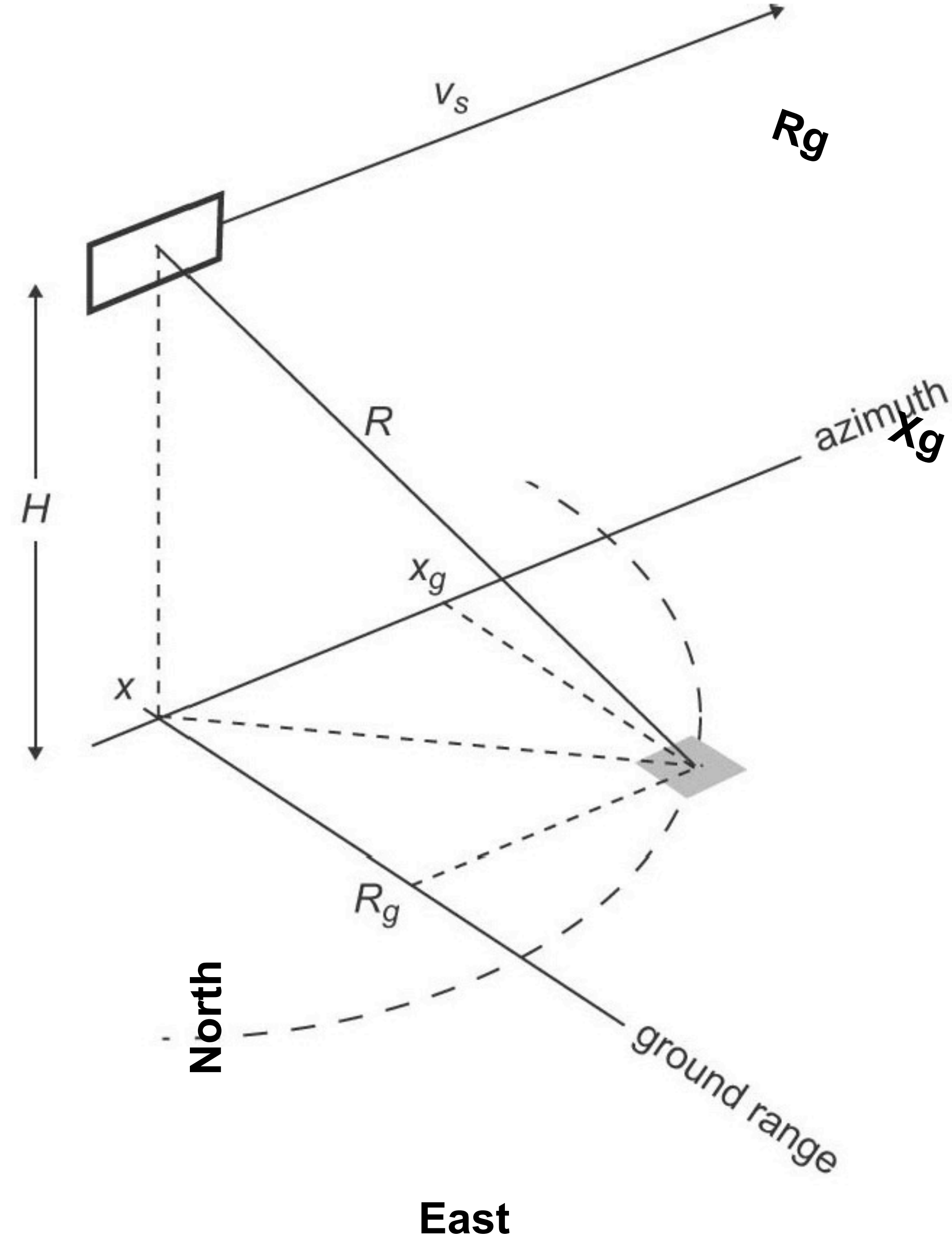
Radar Coordinates

Ground Range Rg:

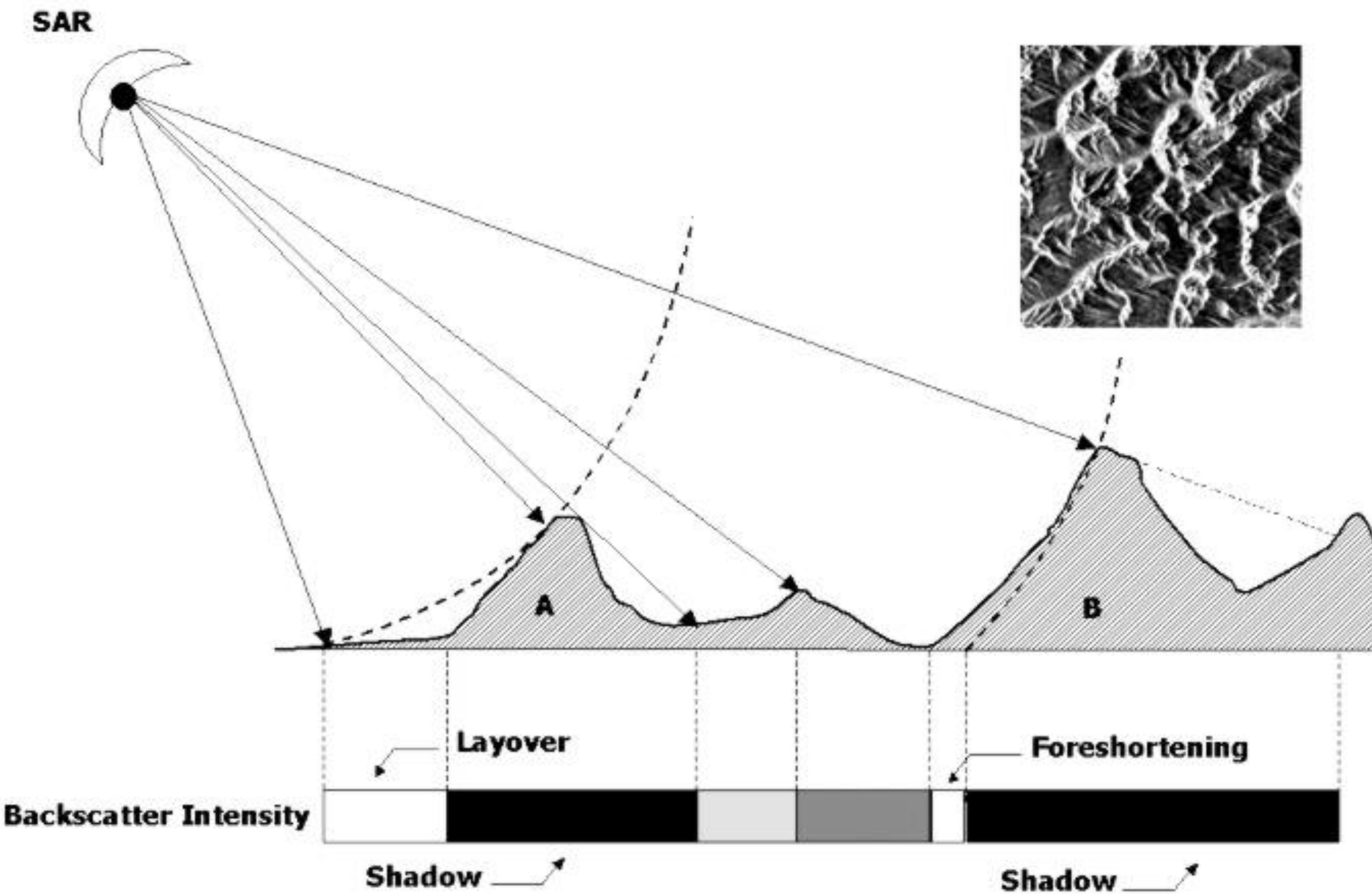
projection of
line of sight
onto ground)

Azimuth Xg:

parallel to
satellite velocity
vector

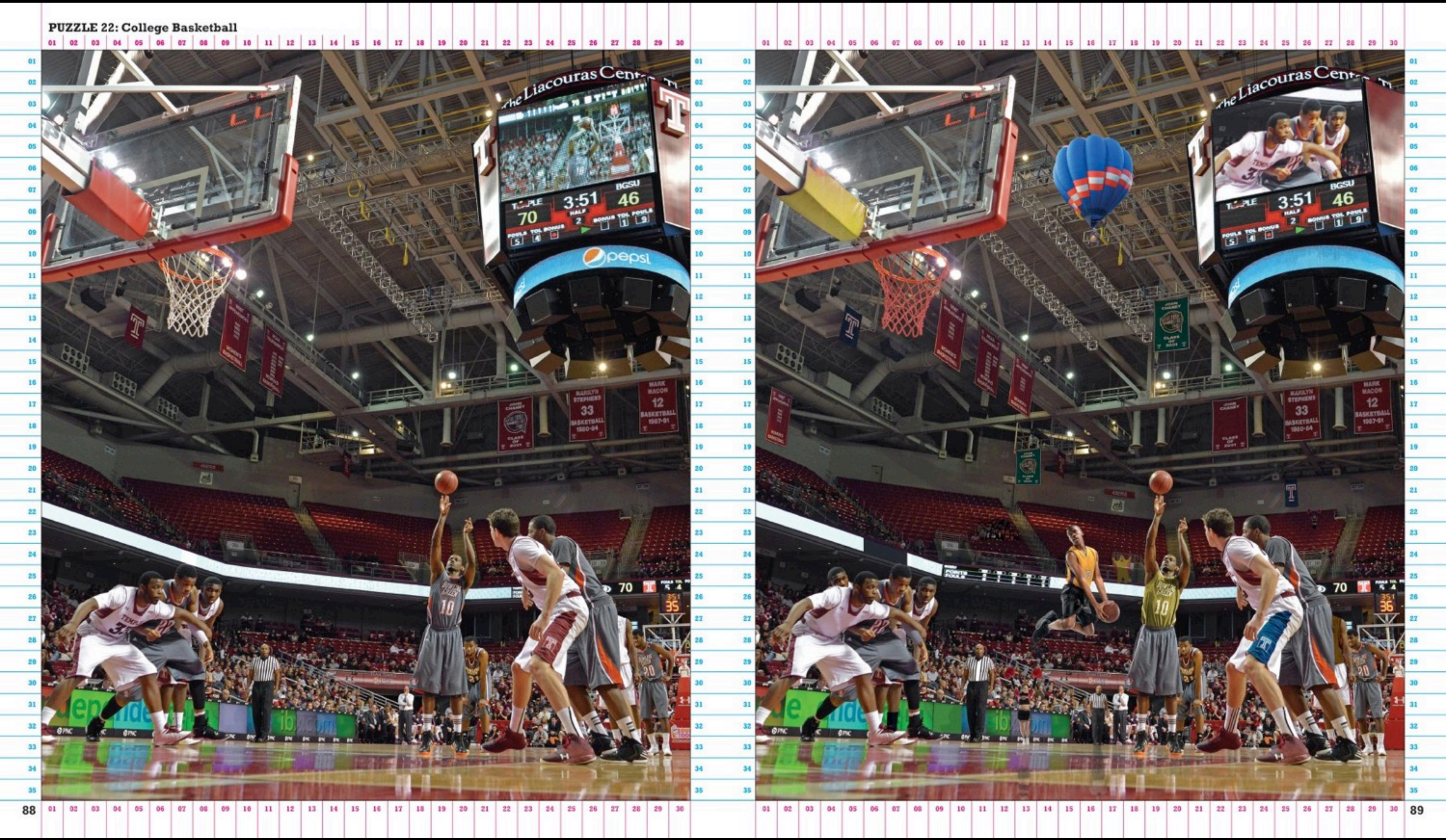


Radar phase measures distance
Radar amplitude measures reflectivity (backscatter intensity)

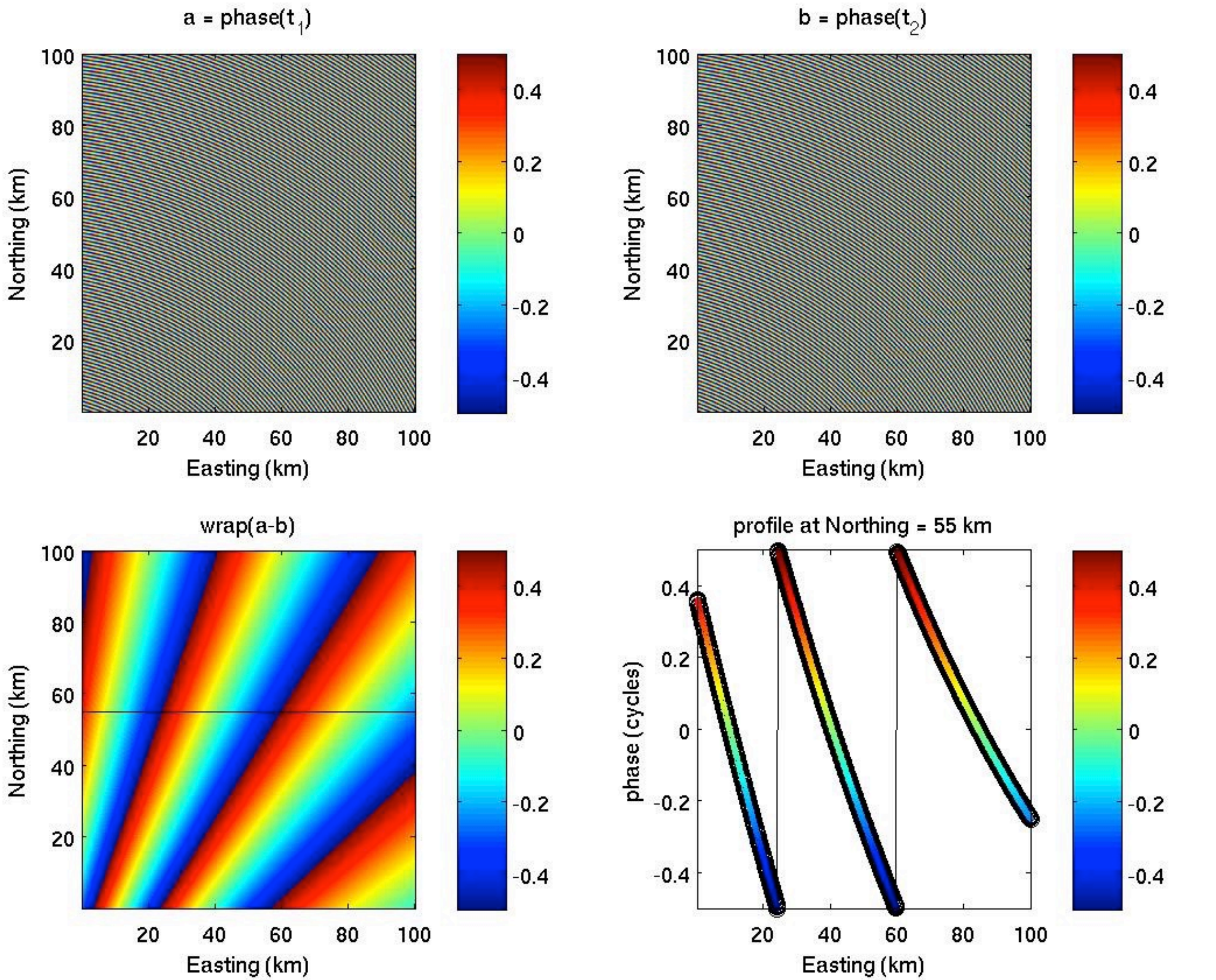


Jeffrey J Hemphill [www. geog.ucsb.edu/~j

INSAR helps spot the differences



Map of phase shift shows fringes

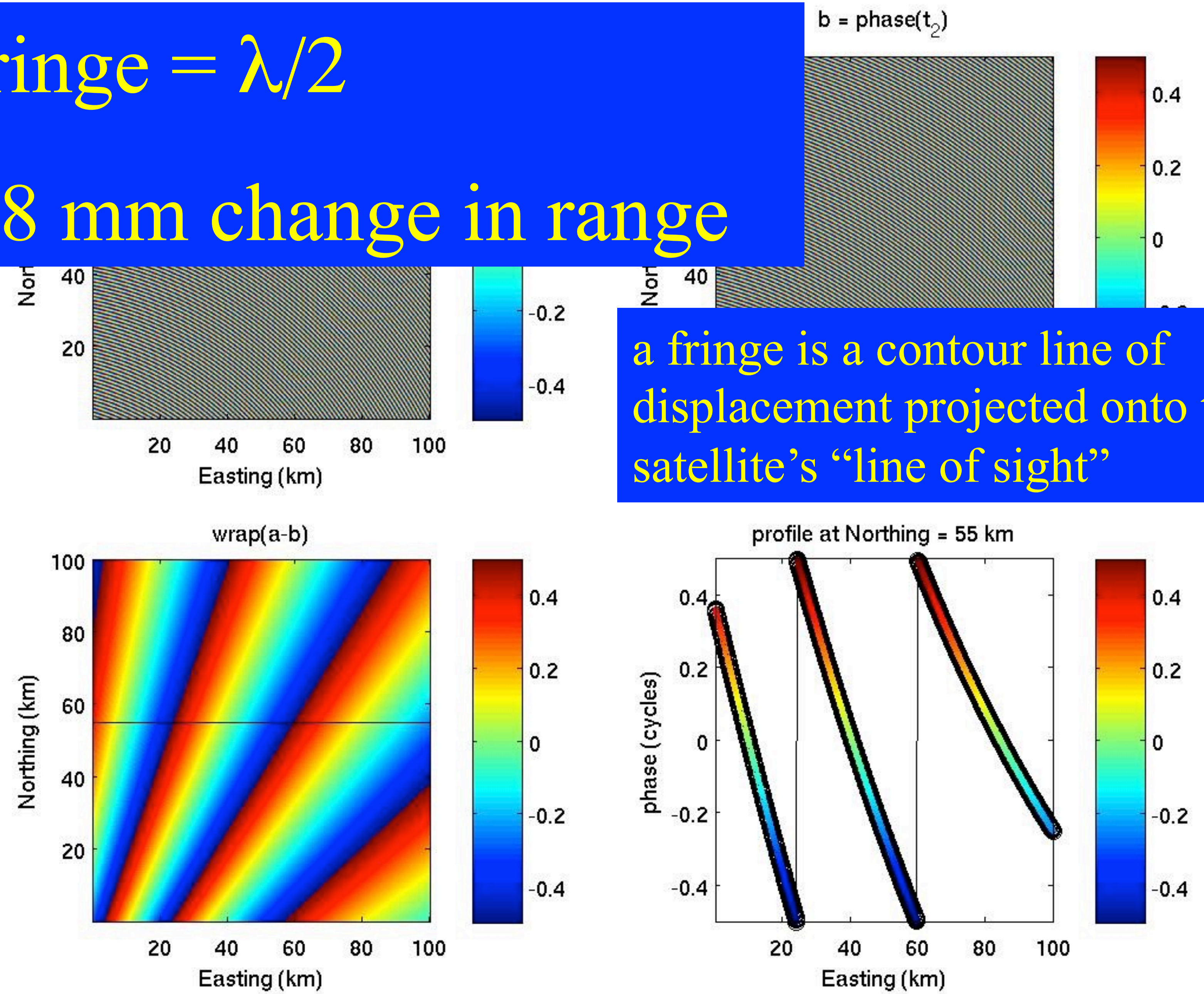


Map of phase shift shows fringes

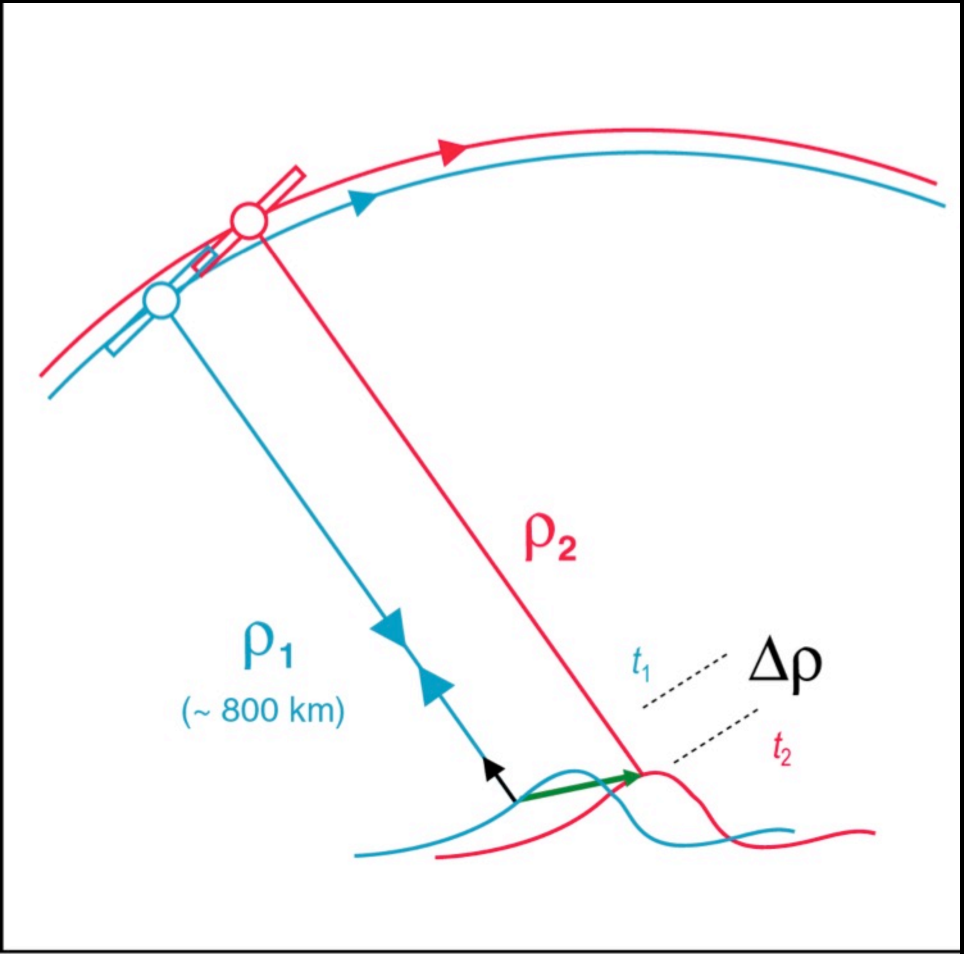
1 fringe = λ/2

= 28 mm change in range

a fringe is a contour line of displacement projected onto the satellite's "line of sight"



INSAR geometry



Range Change

$$\Delta\rho = \frac{\lambda}{2}\left[\phi(t_2) - \phi(t_1)\right]$$

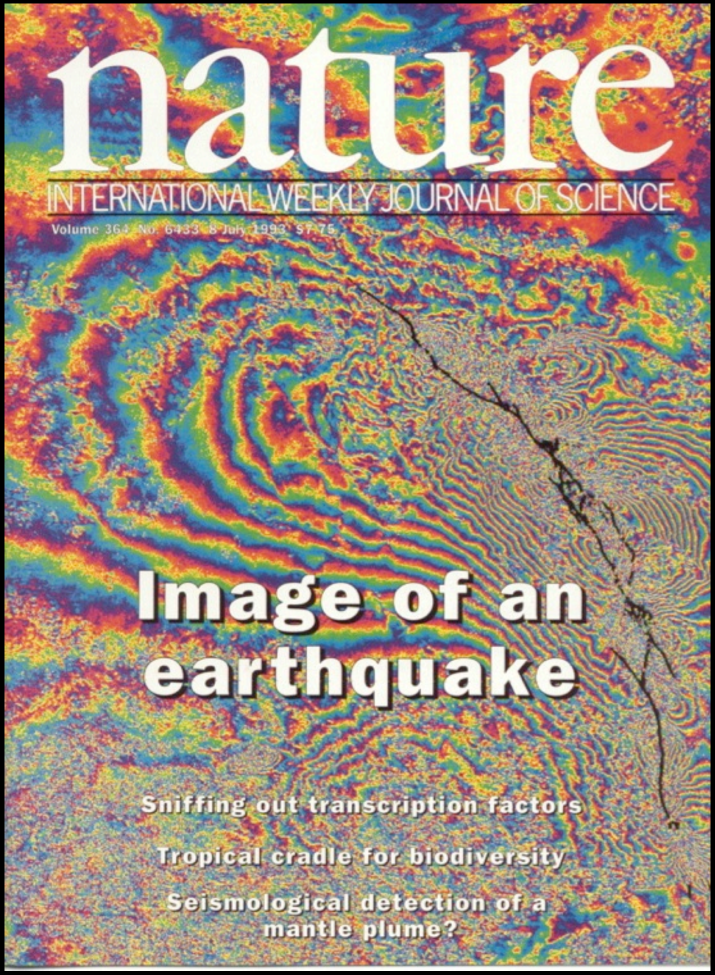
$$\Delta\rho = -\mathbf{u} \bullet \hat{\mathbf{s}}$$

- First image at t_1
- Second image at t_2
- Phase shift => range change
- Component of ground displacement along radar line of sight **s**
- Increasing range Δρ away from satellite
- Range is most sensitive to vertical component of displacement
- Motion parallel to ground track of satellite does not change range

Lucky at Landers => Lessons Learned

« La chance ne sourit qu'aux esprits bien préparés. »

“In the fields of observation, chance favors only the prepared mind.”

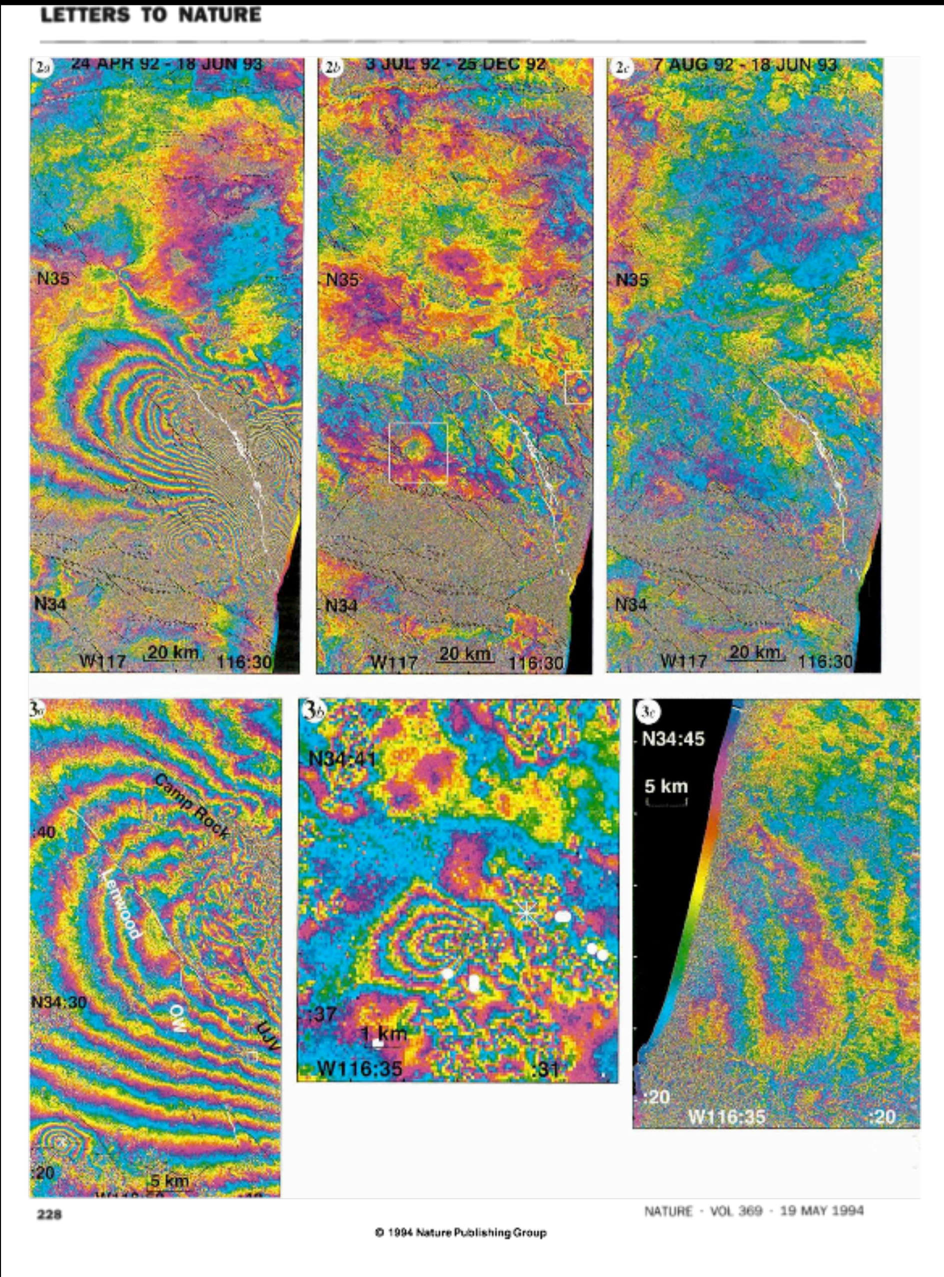


Louis Pasteur
l’Université de Lille(1854)

- **Known signal with ground truth**
- **Large earthquake in arid area**
- **Near download station**
- **Software**
- **International cooperation**
- **Big picture**
- **People**
- **Peer review**

Massonnet, D., M. Rossi, C. Carmona, F. Adragna, G. Peltzer, K. Feigl, and T. Rabaute (1993), The displacement field of the Landers earthquake mapped by radar interferometry, *Nature*, *364*, 138-142. http://dx.doi.org/10.1038/364138a0

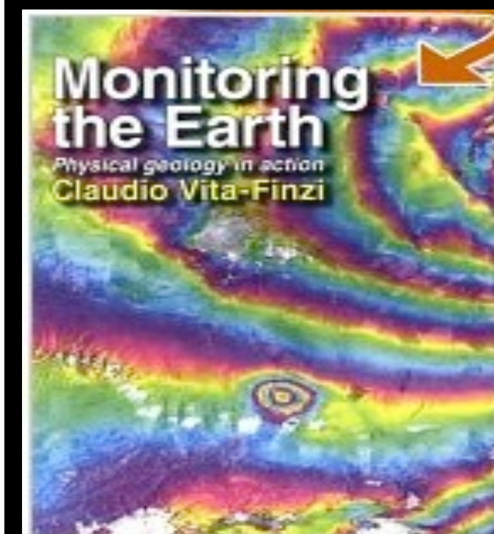
Applying GIPhT to the Fawnskin aftershock

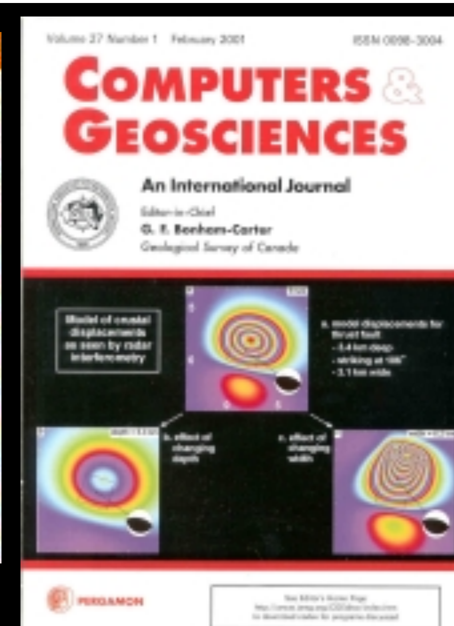


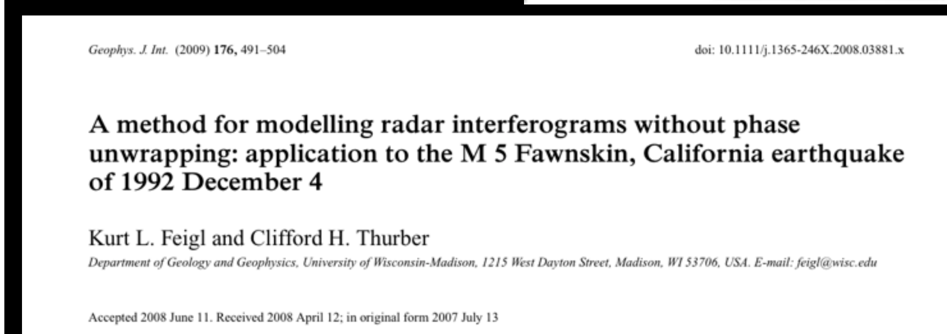

GEOPHYSICAL RESEARCH LETTERS, VOL. 22, NO. 9, PAGES 1037-1040, MAY 1, 1995

Estimation of an earthquake focal mechanism from a satellite radar interferogram: Application to the December 4, 1992 Landers aftershock

Kurt L. Feigl, Arnaud Sergent, and Dominique Jacq
Centre National de la Recherche Scientifique, Toulouse, France





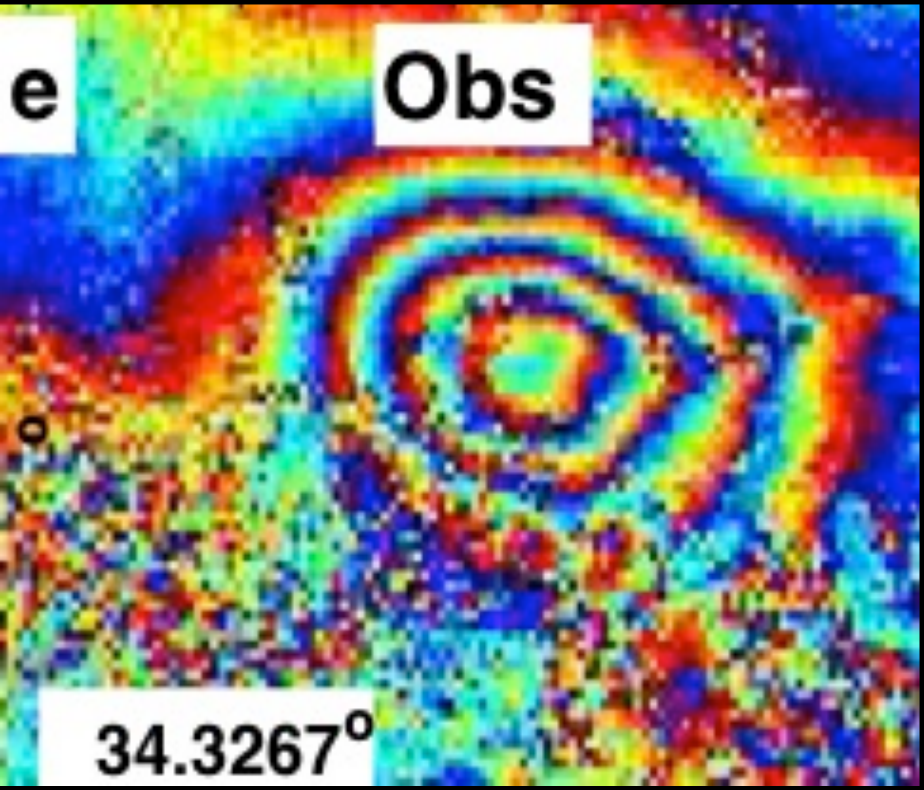

Geophys. J. Int. (2009) 176, 491–504 doi: 10.1111/j.1365-246X.2008.03881.x

A method for modelling radar interferograms without phase unwrapping: application to the M 5 Fawnskin, California earthquake of 1992 December 4

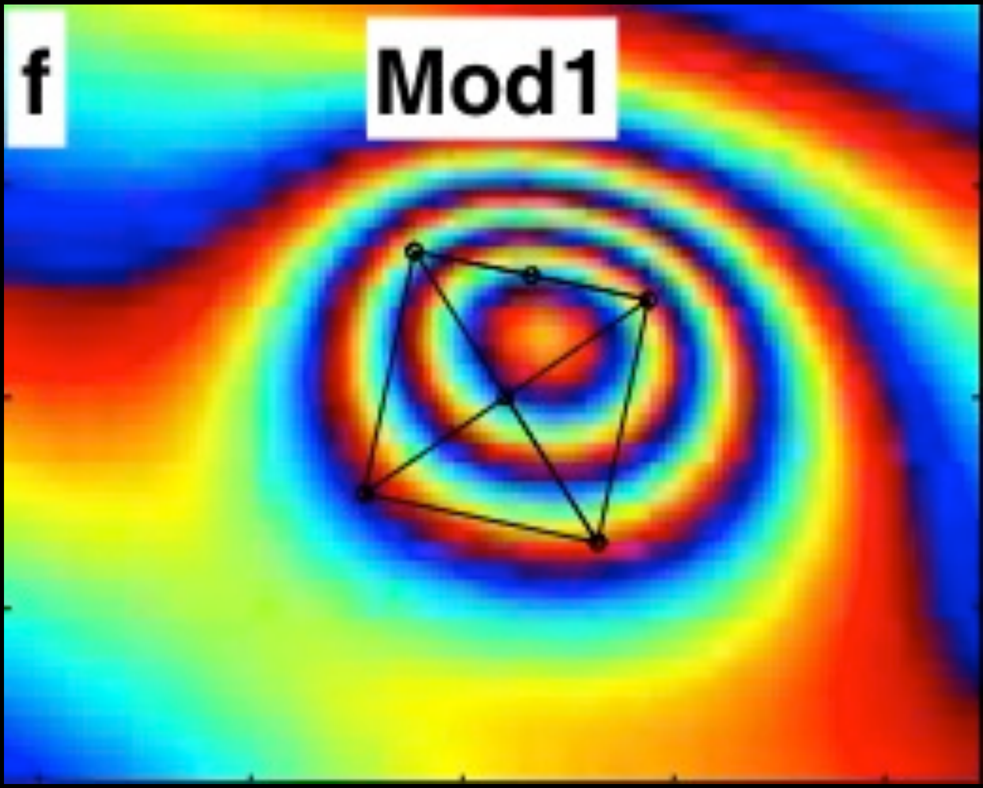
Kurt L. Feigl and Clifford H. Thurber
Department of Geology and Geophysics, University of Wisconsin-Madison, 1215 West Dayton Street, Madison, WI 53706, USA. E-mail: feigl@wisc.edu

Accepted 2008 June 11. Received 2008 April 12; in original form 2007 July 13

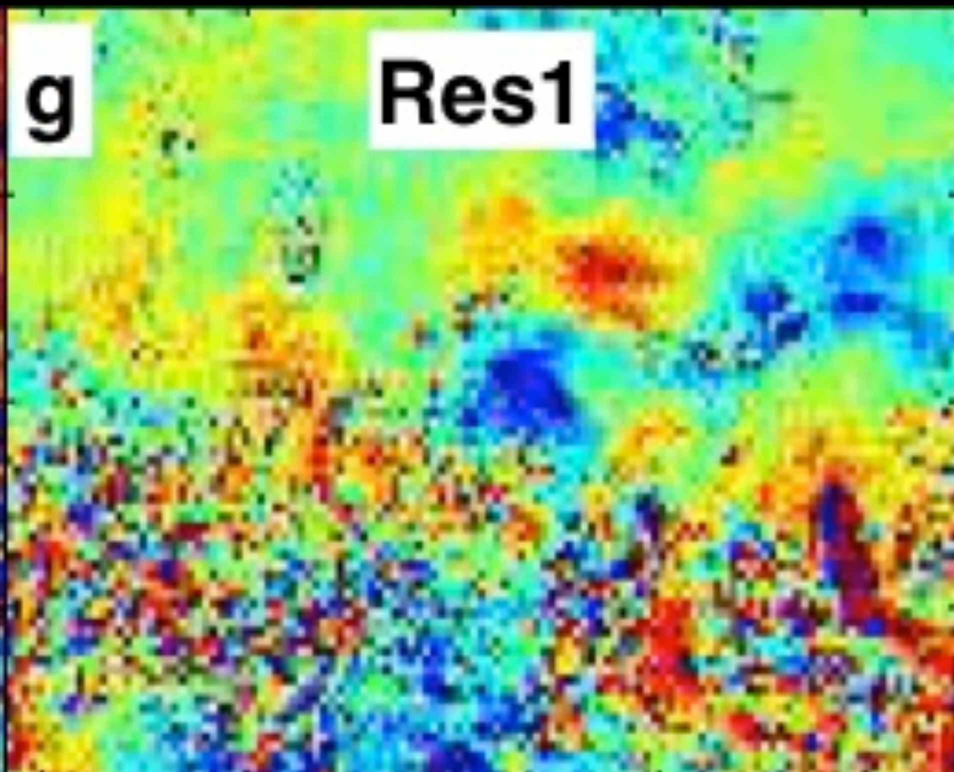
Observed Phase Values

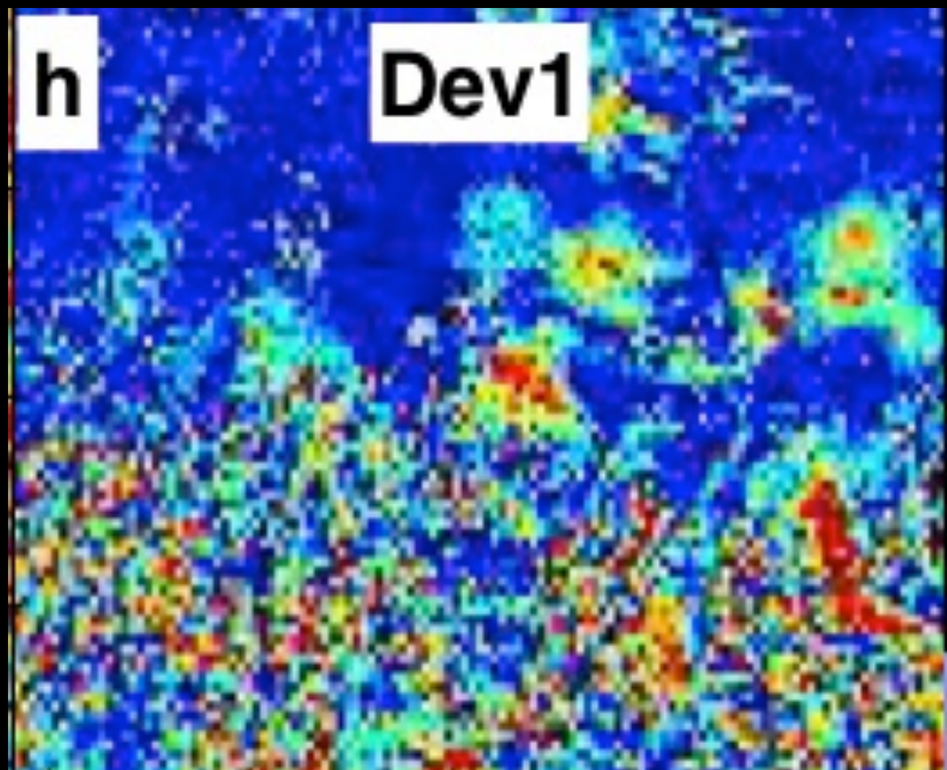


Modeled Phase Values

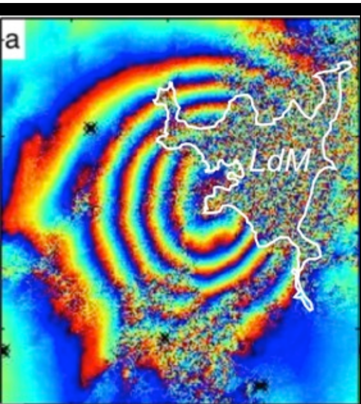


Residual Phase values **Angular deviations**



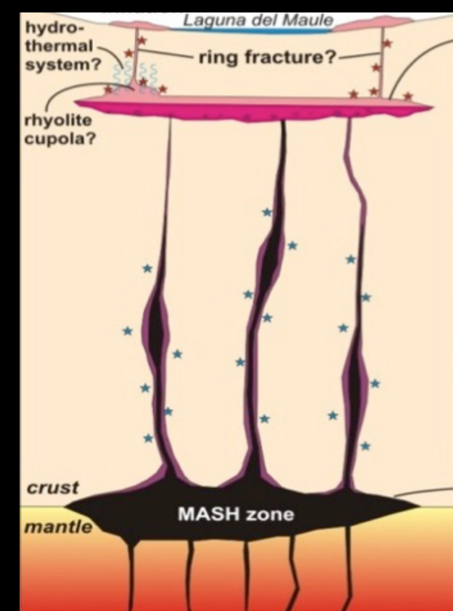


Magmatic Inflation and Potential Caldera Inception in the Andean Cordillera:
Laguna del Maule, Chile

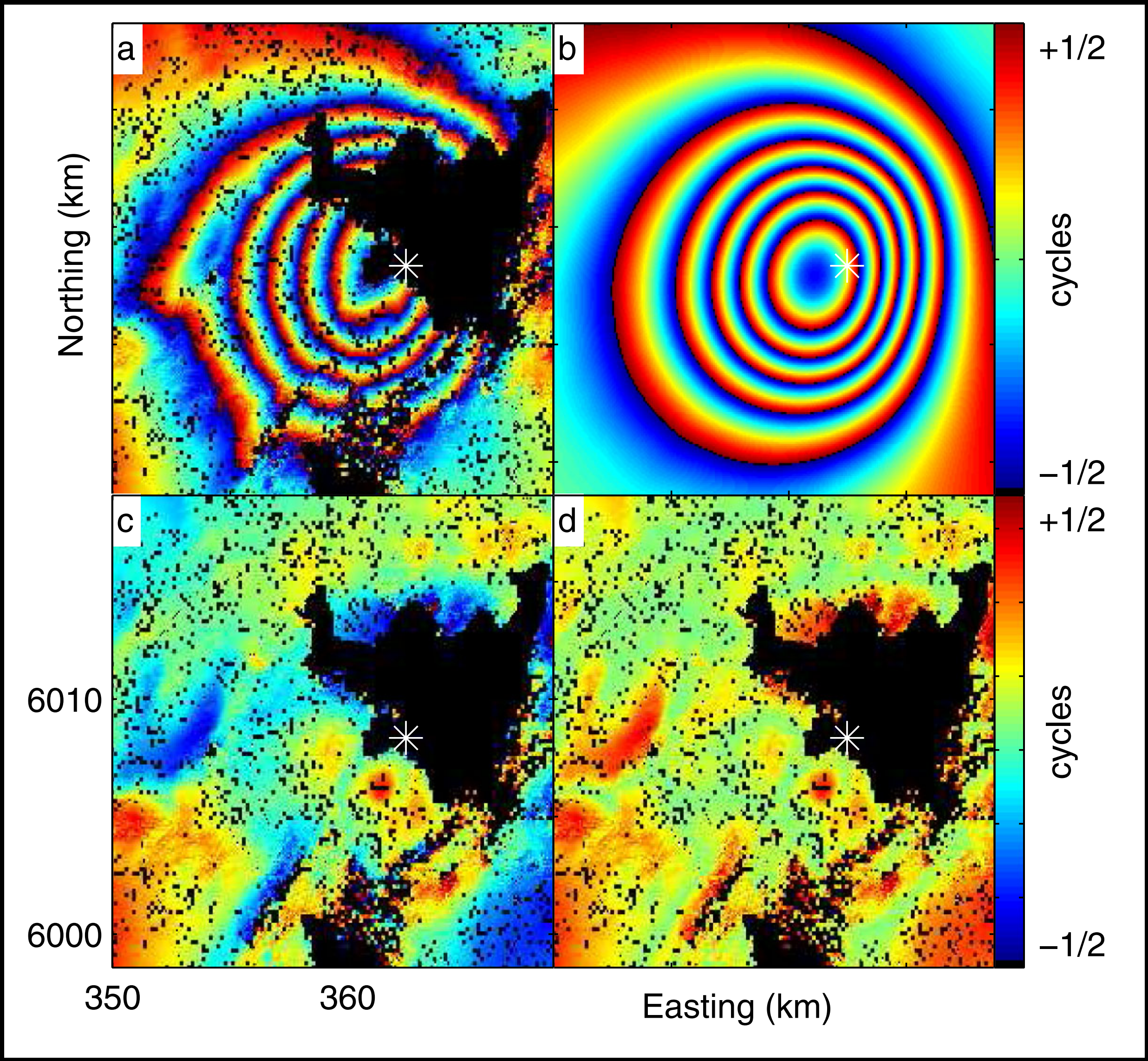


skyscraperlife.com [Jan 31, 2010

EliasMunoz [2008]



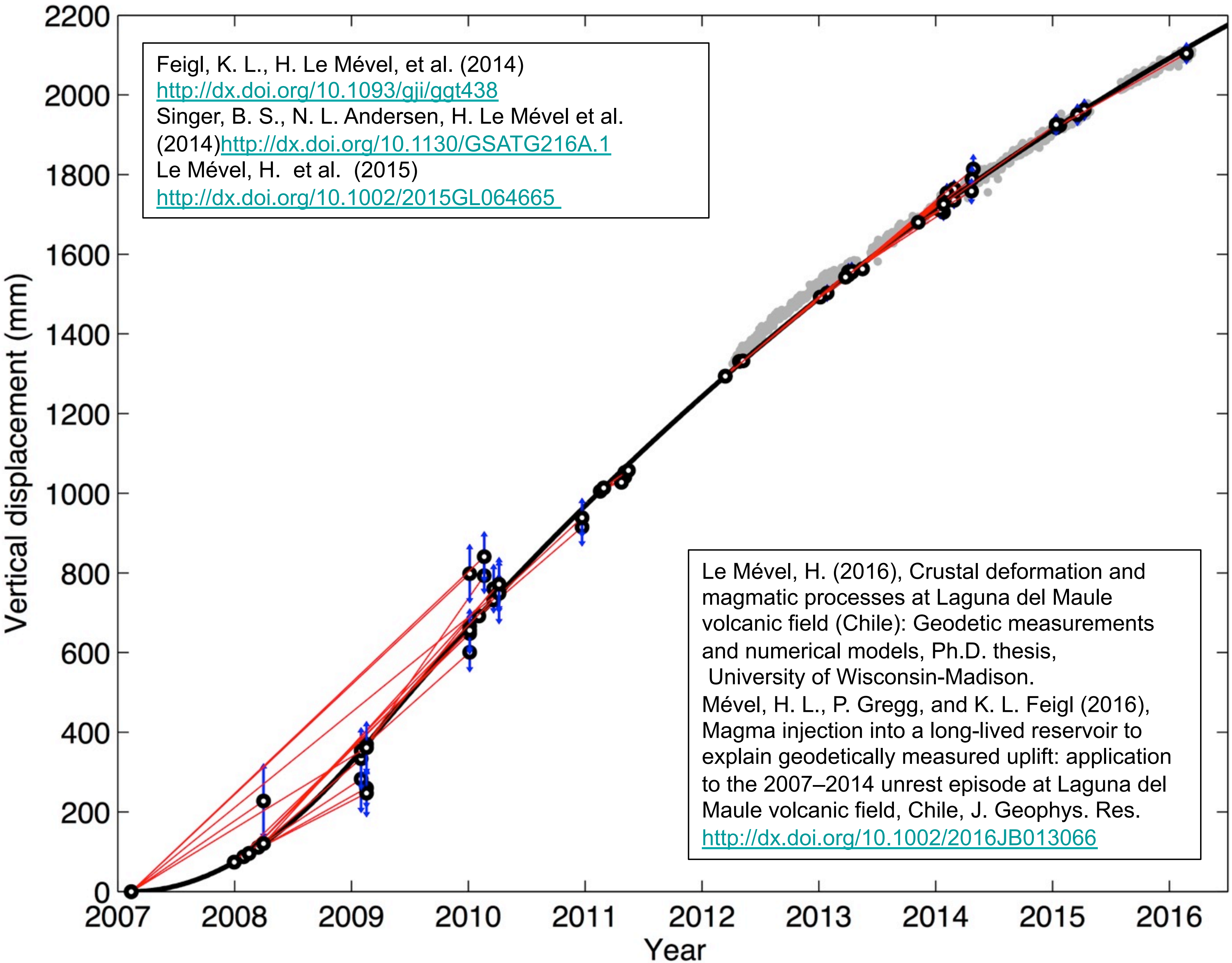
InSAR maps spanning the 1058-day time interval from 2007 Feb. 12 through 2010 Jan. 05.



a. observed phase values;
b. modeled phase values calculated from the final estimate of the parameters in the Okada dislocation model;
c. final residual phase values formed by subtracting final modeled values from observed phase values;
d. angular deviations for final estimate.
One cycle of phase denotes 112 mm of range change.

The ALOS orbit numbers are 5602 and 21035.
The altitude of ambiguity is –72.6 m.

Feigl, K. L., H. Le Mével, S. Tabrez Ali, L. Córdova, N. L. Andersen, C. DeMets, and B. S. Singer (2014), Rapid uplift in Laguna del Maule volcanic field of the Andean Southern Volcanic zone (Chile) 2007–2012, *Geophys. J. Int., 196*, 885-901.
http://dx.doi.org/10.1093/gji/ggt438

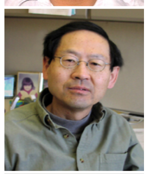

Feigl, K. L., H. Le Mével, et al. (2014)
http://dx.doi.org/10.1093/gji/ggt438
Singer, B. S., N. L. Andersen, H. Le Mével et al.
(2014)http://dx.doi.org/10.1130/GSATG216A.1
Le Mével, H. et al. (2015)
http://dx.doi.org/10.1002/2015GL064665
Le Mével, H. (2016), Crustal deformation and magmatic processes at Laguna del Maule volcanic field (Chile): Geodetic measurements and numerical models, Ph.D. thesis, University of Wisconsin-Madison.
Mével, H. L., P. Gregg, and K. L. Feigl (2016), Magma injection into a long-lived reservoir to explain geodetically measured uplift: application to the 2007–2014 unrest episode at Laguna del Maule volcanic field, Chile, J. Geophys. Res.
http://dx.doi.org/10.1002/2016JB013066
Vertical displacement (mm)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Year

G41B-04: Geodetic measurements and numerical models of deformation at the Svartsengi Geothermal Field, Iceland, 1992 – 2010 [AGU 2012]

Kurt Feigl

Tabrez Ali

Herb Wang



Guðmundur Ómar Friðleifsson

Ómar Sigurðsson

Freysteinn Sigmundsson

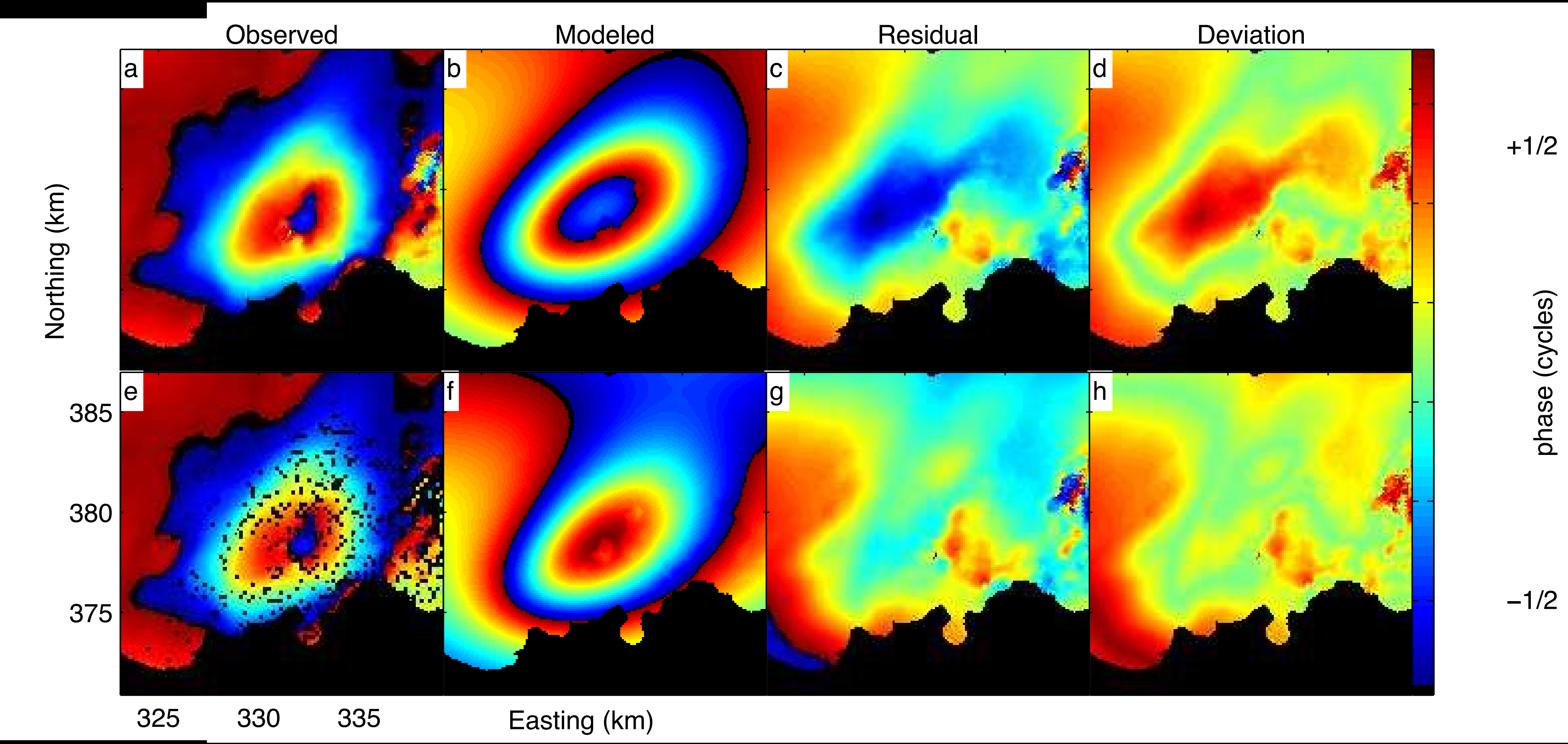
THE UNIVERSITY of WISCONSIN MADISON

HS ORKA HF

SIGILLUM UNIVERSITATIS ISLANDIAE

with data from
ESA, DLR & JAXA

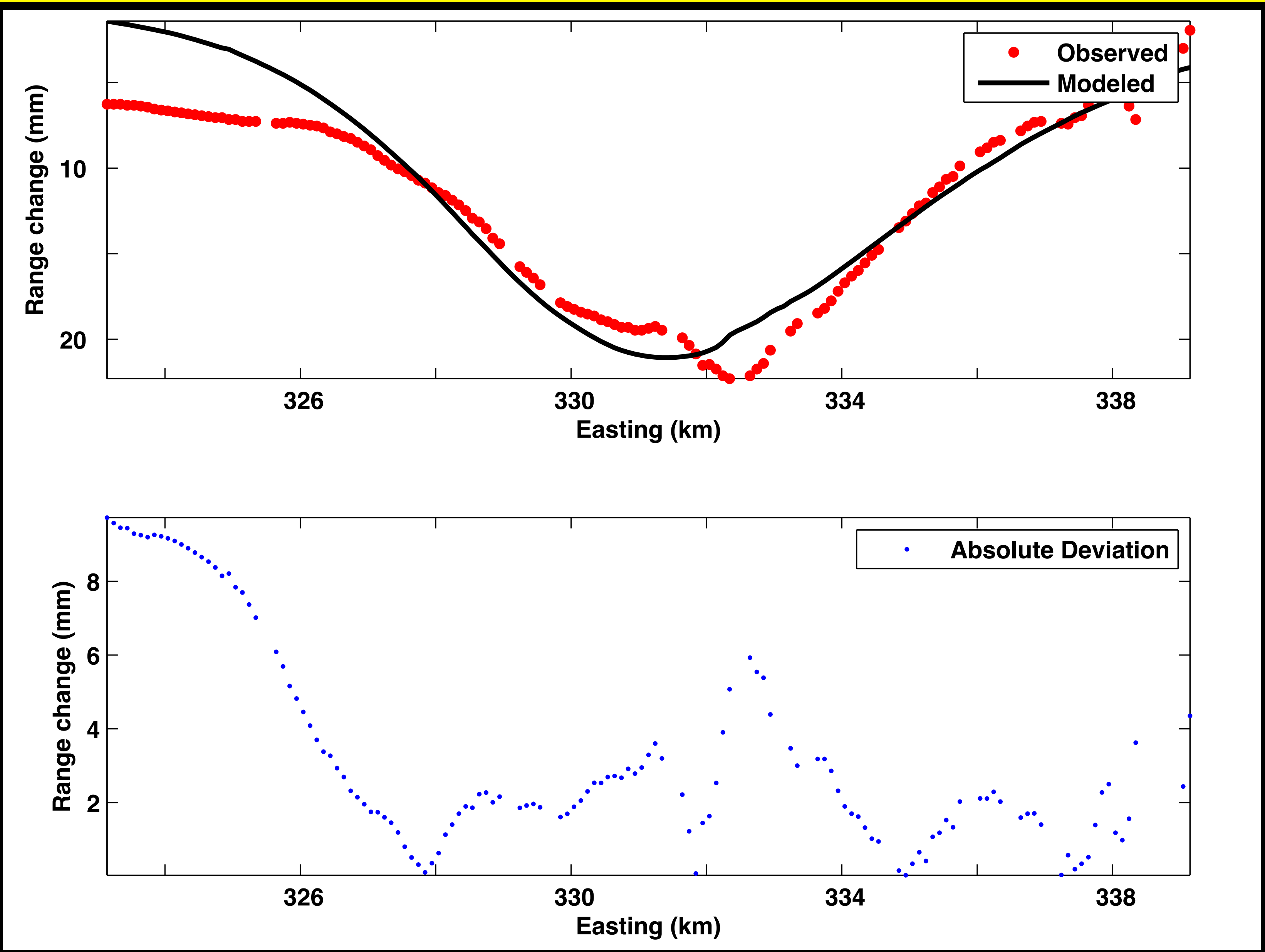
Svartsengi from 1992.5 to 1993.4 Δt = 0.8616 yr (1 fringe = 1 cycle = 28 mm)



Masters, A. E. (2011), Interferometric synthetic aperture radar analysis and elastic modeling of deformation at the Svartsengi geothermal field in Iceland, 1992 to 2010: feasibility of a reverse impulse-response evaluation of reservoir pressure from low Earth orbit, M.S. (Geophysics) thesis, University of Wisconsin, Madison.

Kurt Feigl

Svartsengi from 1992.5 to 1993.4 Δt = 0.8616 yr (1 fringe = 1 cycle = 28 mm)



Masters, A. E. (2011), M.S. (Geophysics) thesis, University of Wisconsin, Madison.

Kurt Feigl

Time-Dependent Deformation at Brady Hot Springs Geothermal Field (Nevada) Measured With Interferometric Synthetic Aperture Radar and Modeled with Multiple Working Hypotheses of Coupled Behavior (#T13E-02)

Kurt L. Feigl[1]
S. Tabrez Ali [1]
John Akerly [4]
E. C. Baluyut[1]
Michael Cardiff [1]
Dante Fratta[1]
William Foxall [2]
Corné Kreemer [5]
Robert J. Mellors [3]
Christina Morency[3]
Janice Lopeman [4]
Paul Spielman [4]
Herbert F. Wang [1]

1. U. Wisconsin-Madison
2. Berkeley N.L.
3. Livermore N.L.
4. Ormat Technologies, Inc.
5. U. Nevada-Reno
6. Silixa Ltd.
7. Temple U.

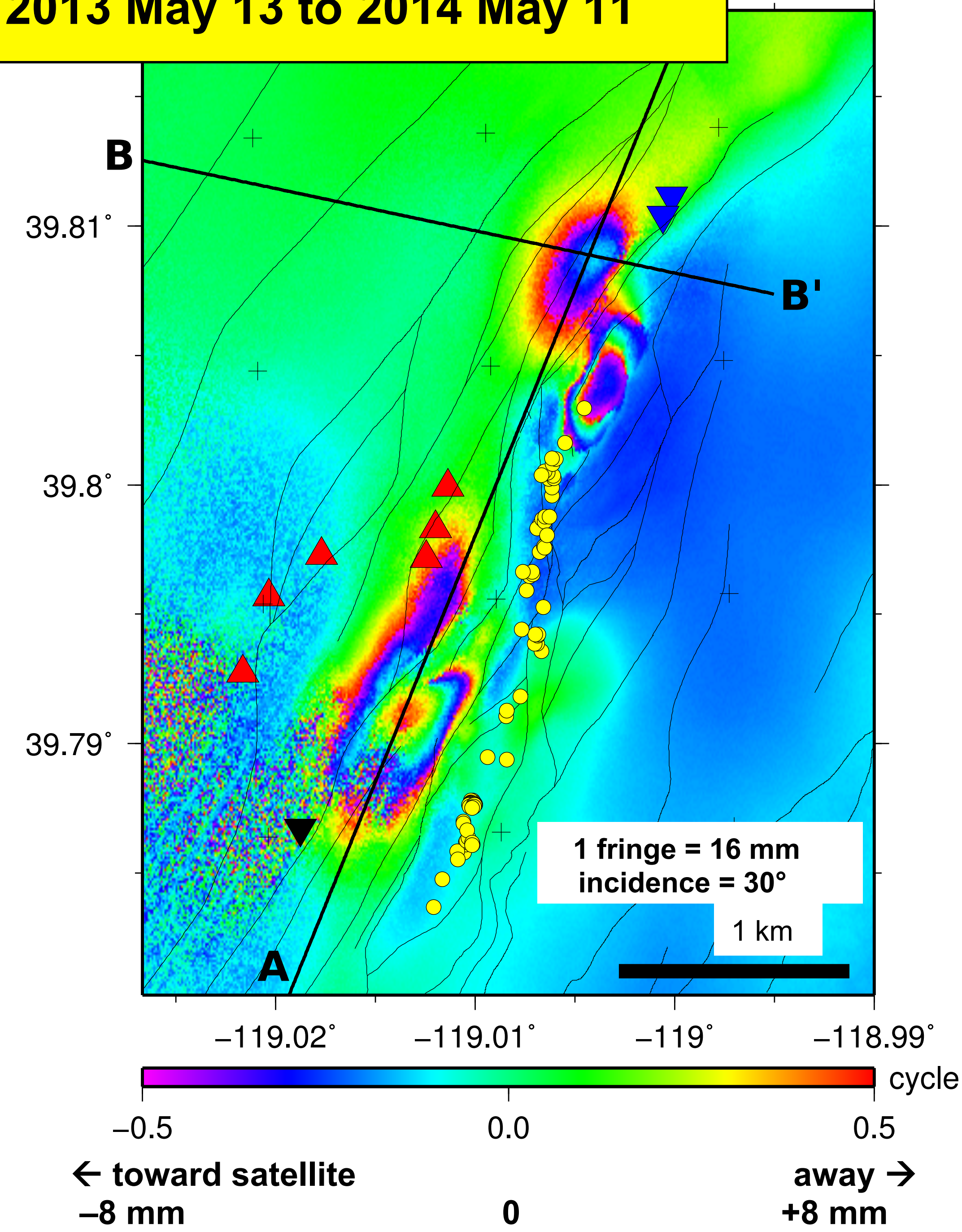
Ali, S. T., J. Akerley, E. C. Baluyut, M. Cardiff, N. C. Davatzes, K. L. Feigl, W. Foxall, D. Fratta, R. J. Mellors, P. Spielman, H. F. Wang, and E. Zemach (2016), Time-series analysis of surface deformation at Brady Hot Springs geothermal field (Nevada) using interferometric synthetic aperture radar, *Geothermics*, 61, 114-120.
http://dx.doi.org/10.1016/j.geothermics.2016.01.008

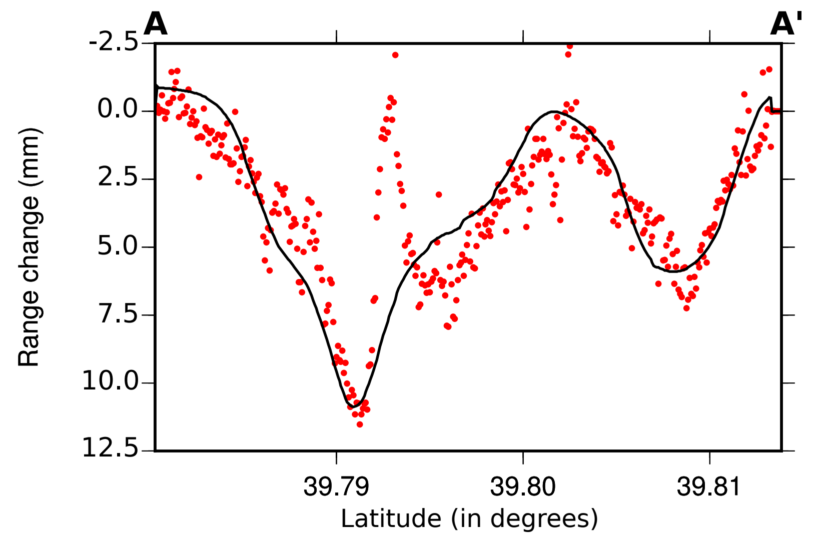
Sponsors:	**DOE:**	**InSAR & MEQ (Nicholas Davatzes et al.)**	**DE-EE0005510**
		PoroTomo (Kurt Feigl et al.)	**DE-EE0006760**
	NASA:	**NISAR Science Definition Team (Kurt Feigl)**	**NNX12AO37G**
SAR data:	**DLR:**	**TerraSAR-X and TanDEM-X**	**RES1236**
	JAXA:	**ALOS**	**NASA DAAC at ASF**
	ESA:	**ERS & ENVISAT**	**WINSAR**

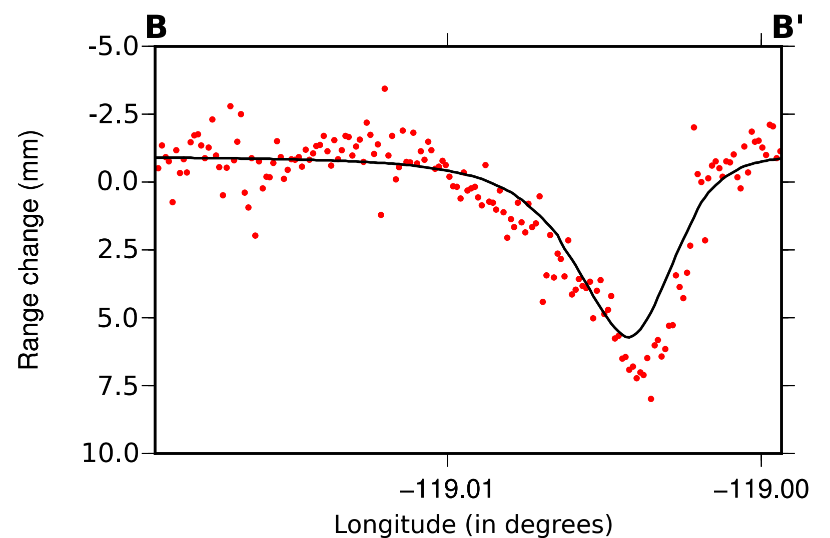
2013 May 13 to 2014 May 11

Subsidence in 2 bowls:

- dimension ~ 1 km
- near injection wells
- near production wells
- not centered on wells

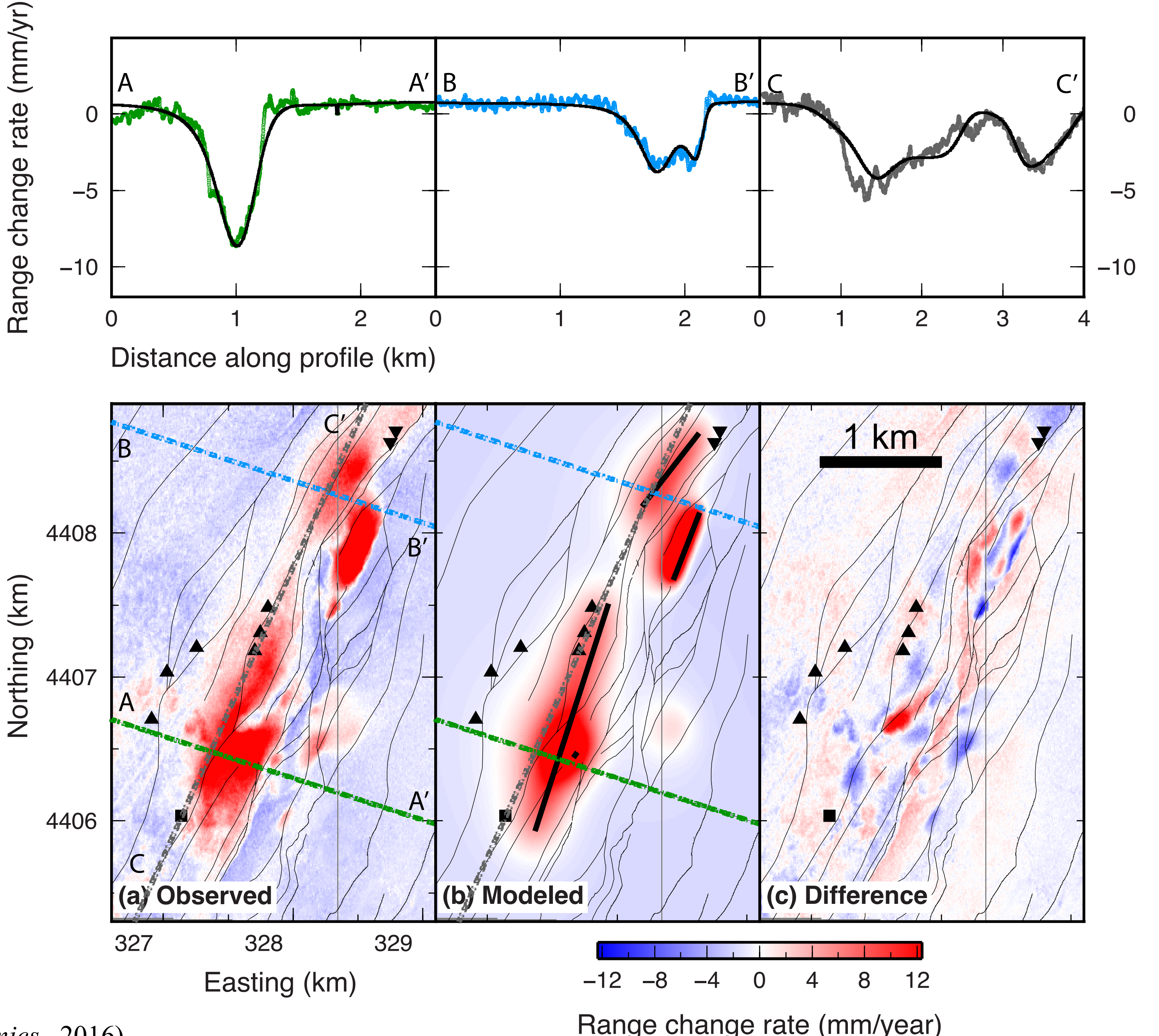






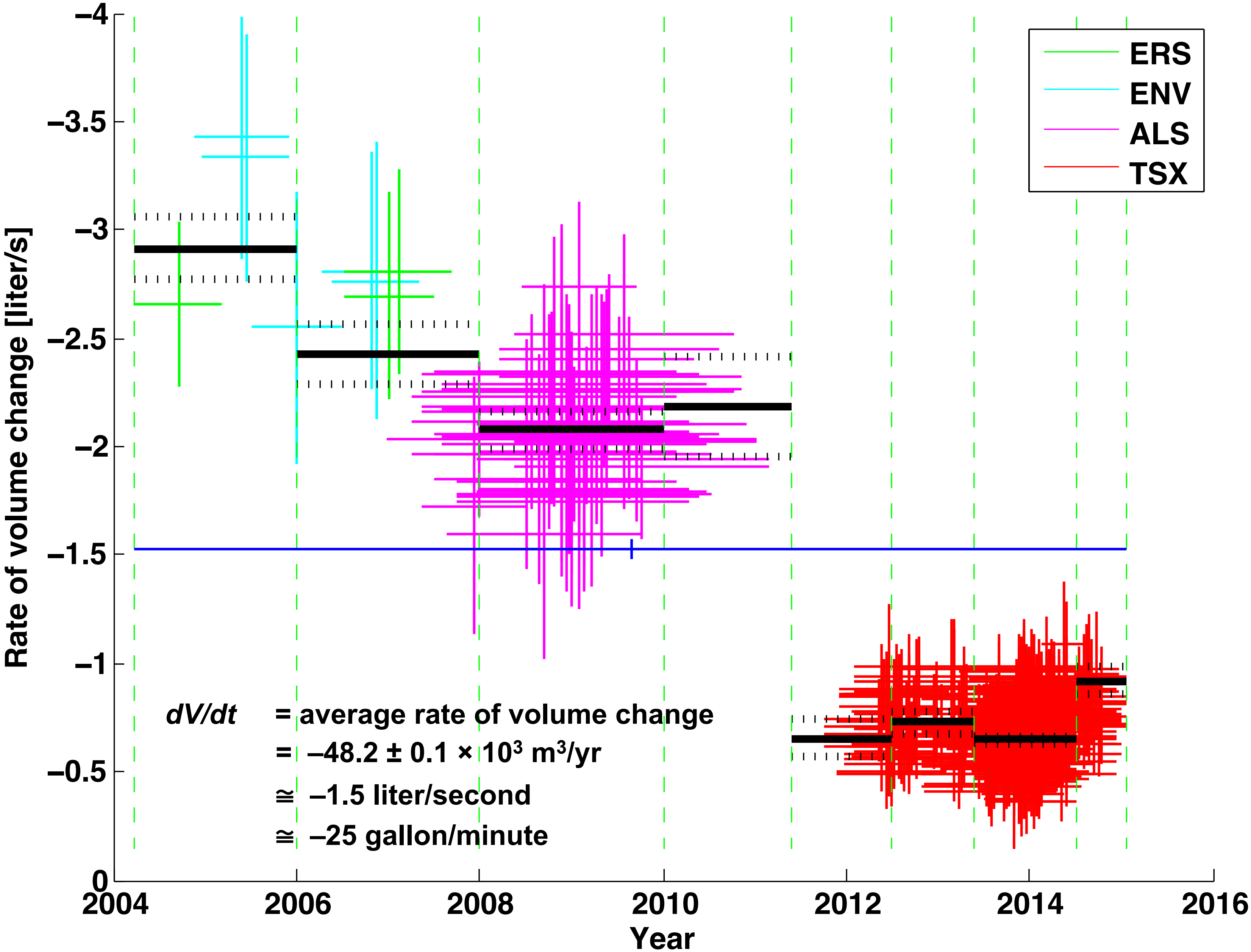
range change rate

2011 to 2015



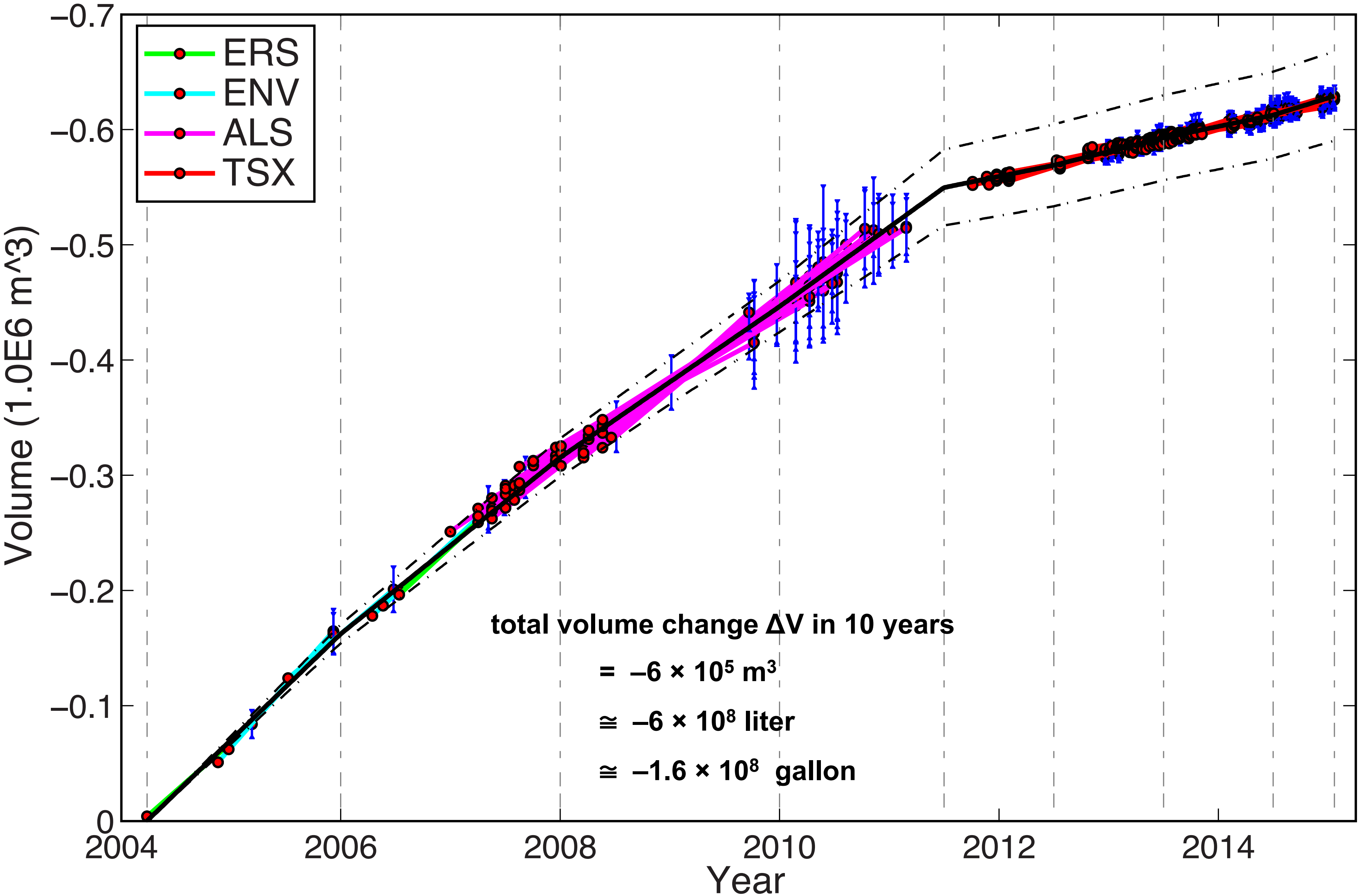
Ali et al. (*Geothermics*,. 2016)

rate of volume change estimated from InSAR



Ali et al. (*Geothermics*,. 2016)

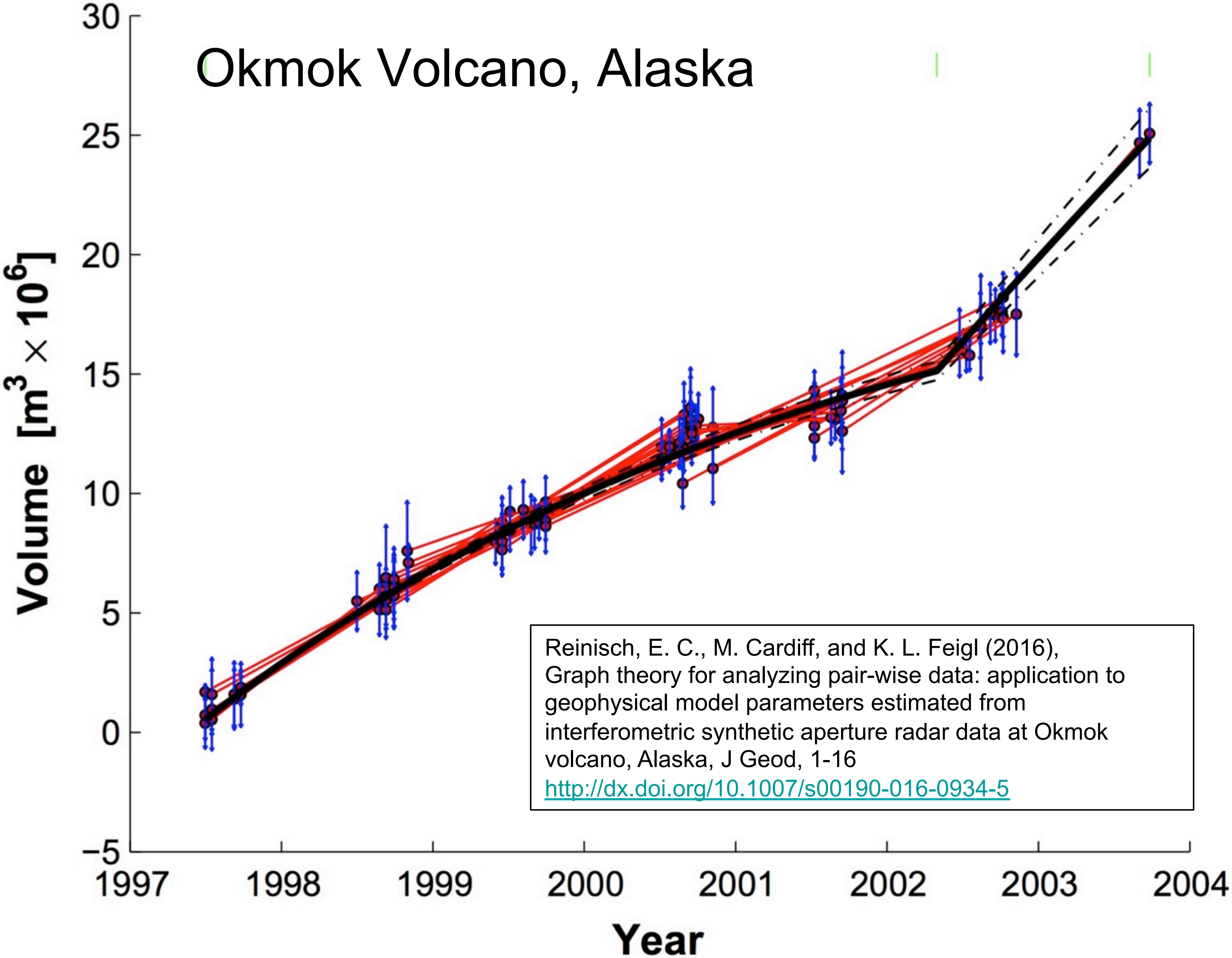
Modeled cumulative volume change



Ali et al. (*Geothermics*,. 2016)

Okmok Volcano, Alaska

Eruption of Okmok, photo taken Sunday, July 13, 2008 by Kelly Reeves [Alaska Airlines]


Okmok Volcano, Alaska
Volume [m^3 × 10^6]
30
25
20
15
10
5
0
−5
1997
1998
1999
2000
2001
2002
2003
2004
Year
Reinisch, E. C., M. Cardiff, and K. L. Feigl (2016),
Graph theory for analyzing pair-wise data: application to
geophysical model parameters estimated from
interferometric synthetic aperture radar data at Okmok
volcano, Alaska, J Geod, 1-16
http://dx.doi.org/10.1007/s00190-016-0934-5


2010.03.24 - Guðrún Sverrisdóttir


2010.04.21 - Þórdís Högnadóttir

2 Eruptions in 2010 at Eyjafjallajökull in Iceland:
- basalt on flank (20 March – 12 April)
- trachyandesite at summit (14 April - 22 May)

Literally means “the glacier of the island mountains”
- Eyja [island] fjalla [mountains] jökull [glacier]

Kurt Feigl and Peter Sobol installed 3 UW broadband seismometers for ambient noise tomography


2010-05-23 Kurt Feigl

Intrusion triggering of the 2010 Eyjafjallajökull explosive eruption

F Sigmundsson *et al*. *Nature* **468**, 426-430 (2010)

The cover photo shows the base of the ash plume in the main crater on 11 May 2010, with hot 'bombs' of lava being ejected hundreds of metres into the air. Credit: Fredrik Holm (www.fredrikholm.se)

RESEARCH LETTER

Full Methods and any associated references are available in the online version of the paper at www.nature.com/nature.

Received 14 May; accepted 5 October 2010.

nature

Click here for full article:
http://dx.doi.org/10.1038/nature09558
Click here for supplementary information:
http://www.nature.com/nature/journal/v468/n7322/abs/nature09558.html#supplementary-information

Models of intrusions, sills, and dikes

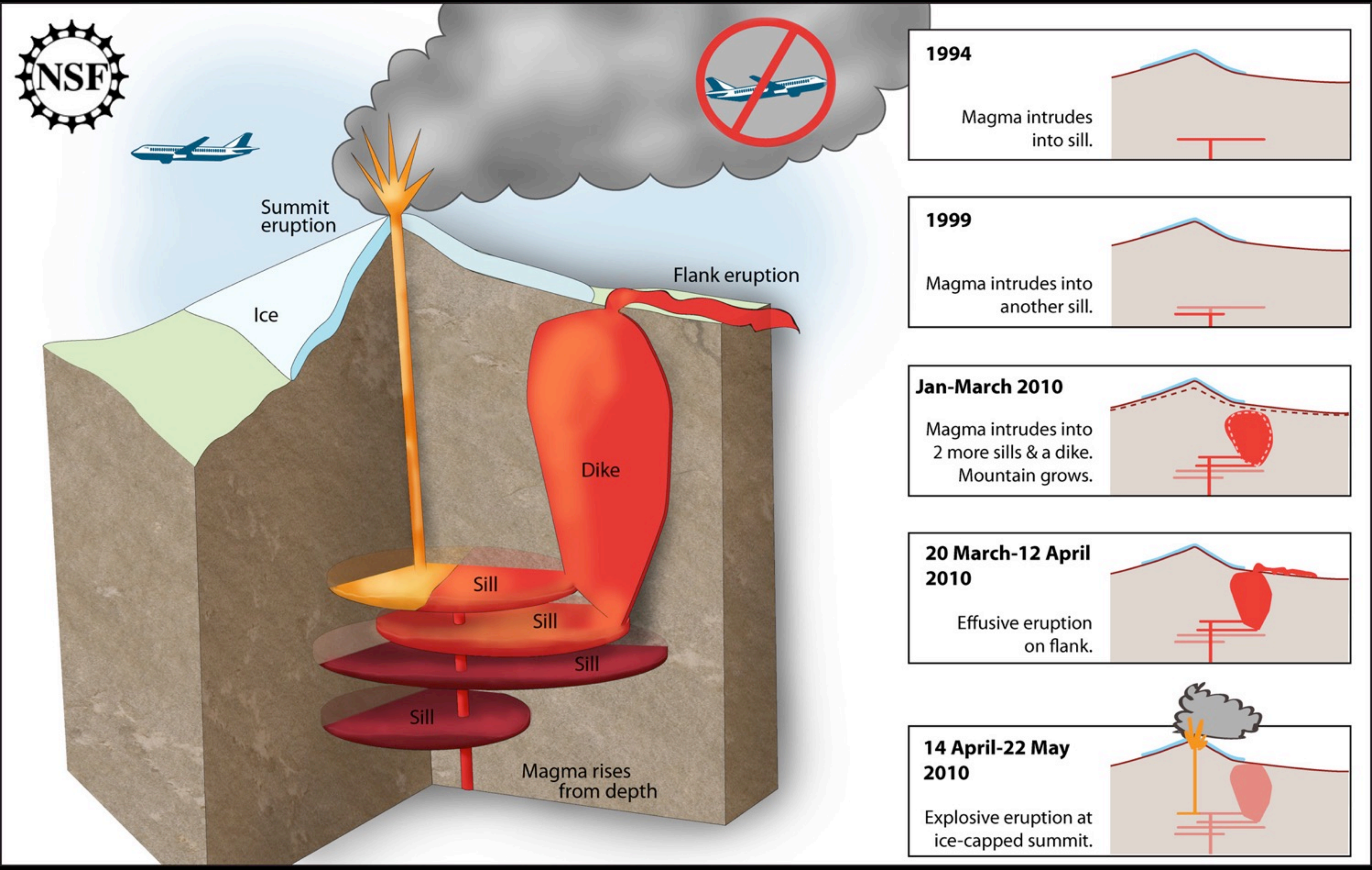


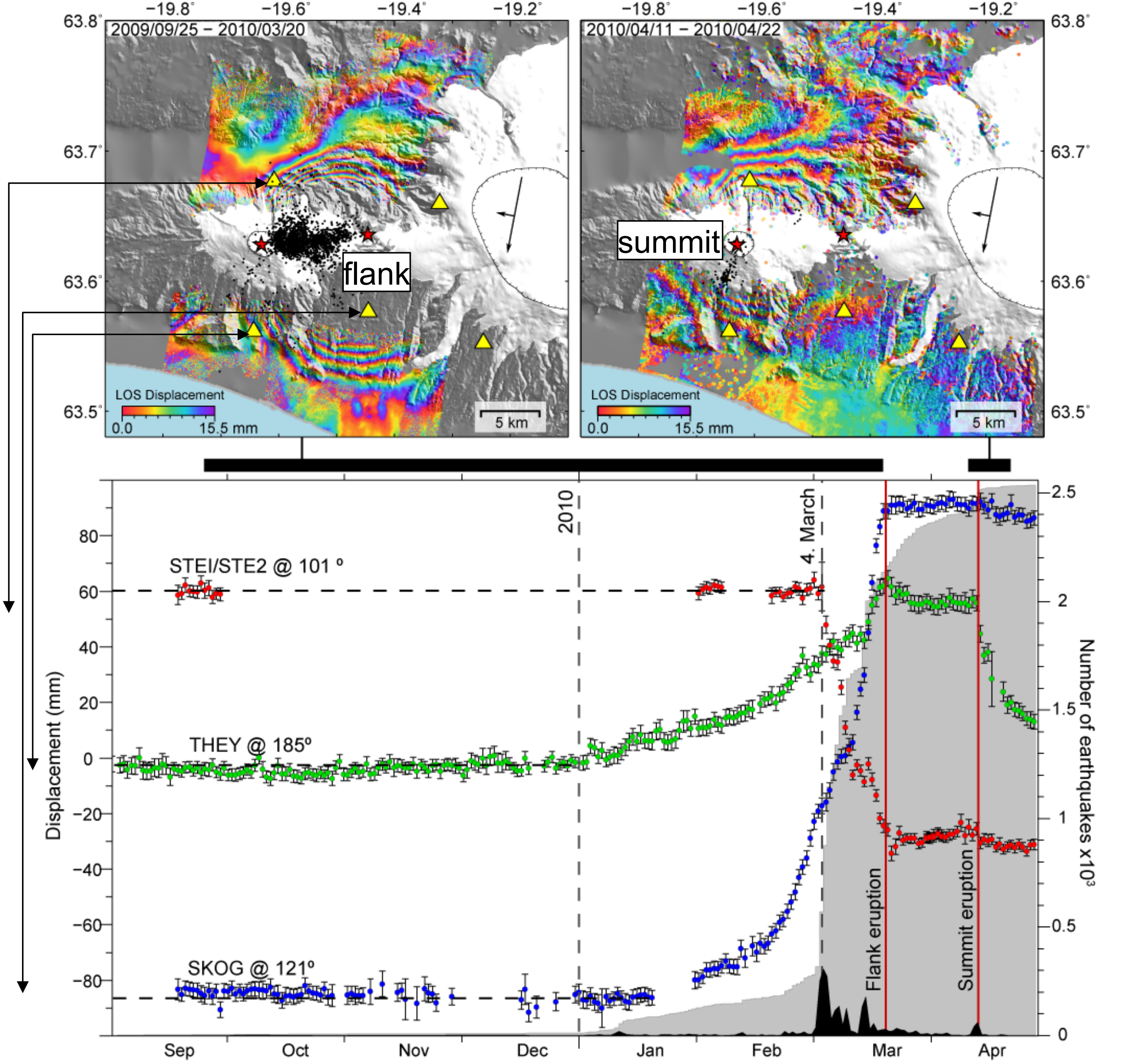
Illustration by Zina Deretksky, U.S. National Science Foundation (NSF)

Intrusion triggering of the 2010 Eyjafjallajökull explosive eruption

InSAR
TerraSAR-X
15.5 mm/fringe

GPS

N(quakes)



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