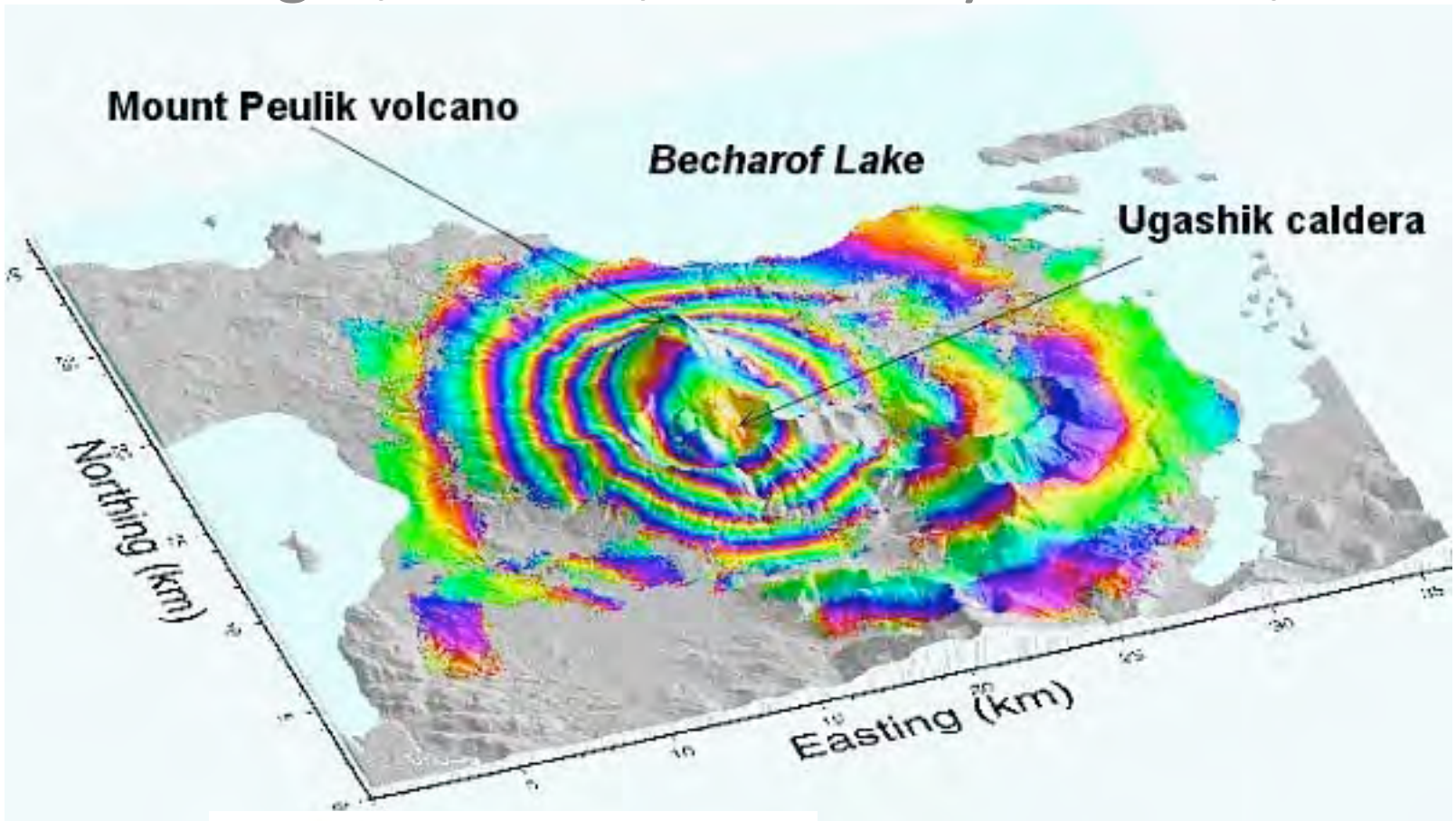
Using EO for volcanoes

Tim Wright, COMET, University of Leeds, UK



NERC SCIENCE OF THE ENVIRONMENT

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Part (a): What do volcanologists want to know?

Q1 Where is the magma?

Q2 Has a volcano erupted?

Q3 How much has erupted?

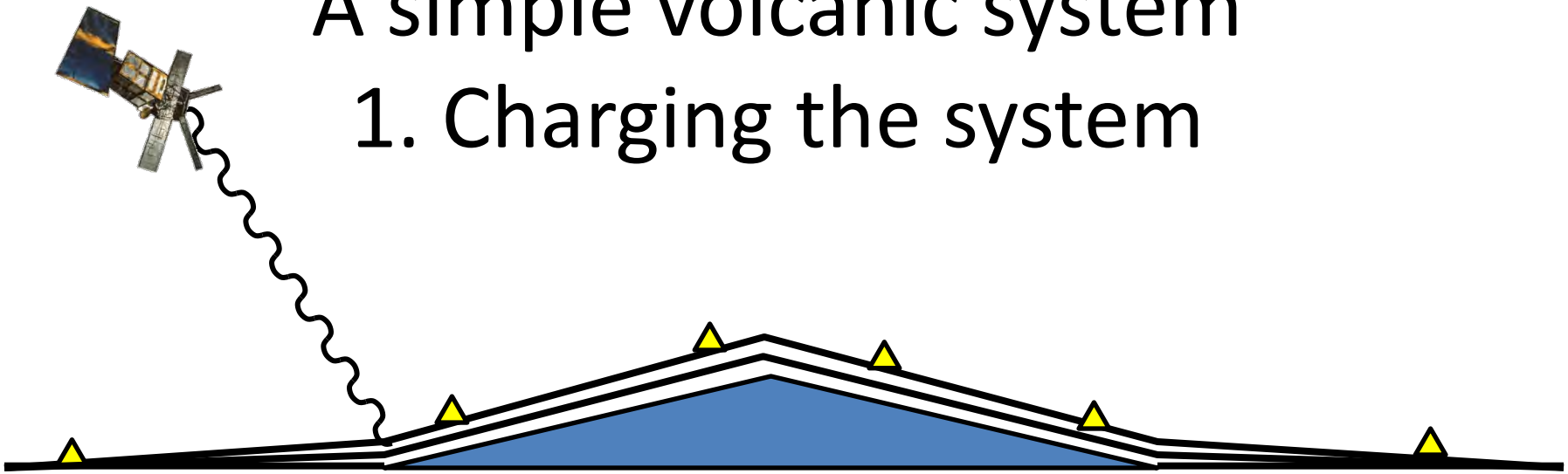
Q4 What will happen next?

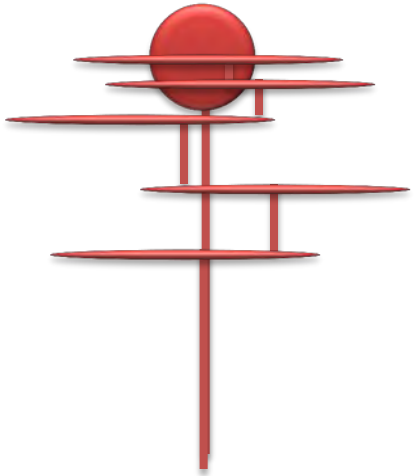
Q5 What is the probability of a volcano erupting?

EO data critical in answering these questions

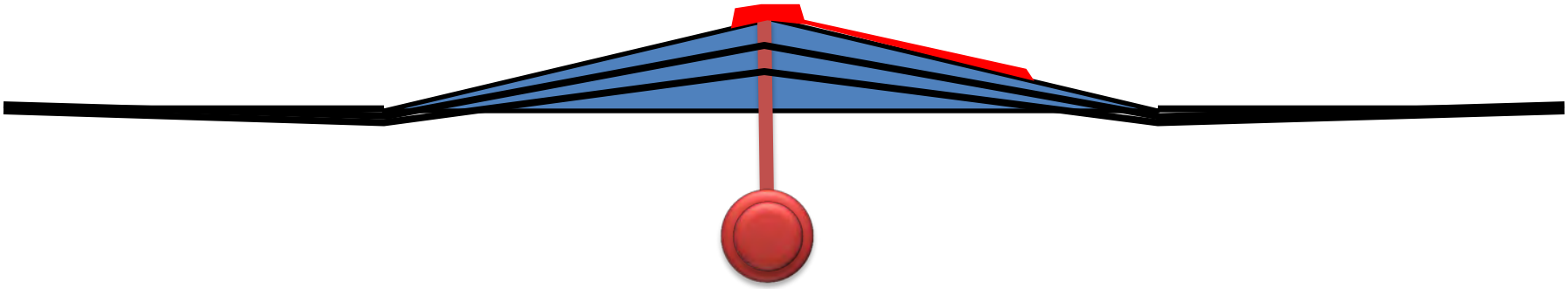
Q1 Where is the magma?

A simple volcanic system
1. Charging the system

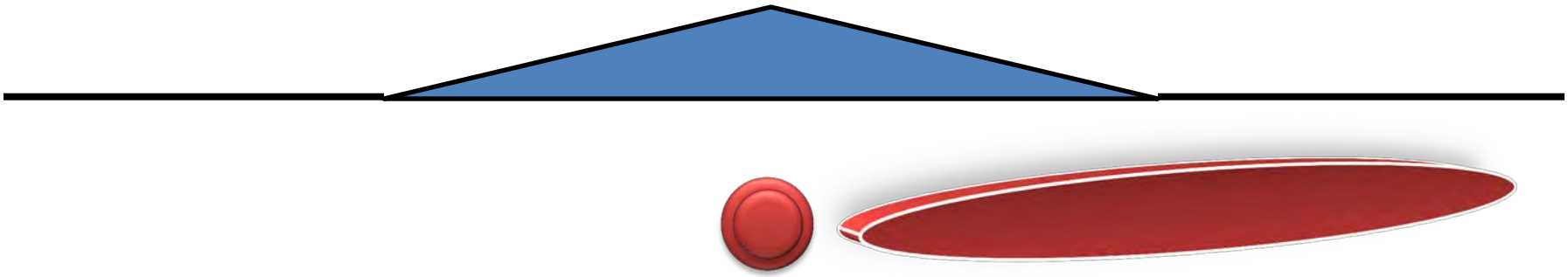


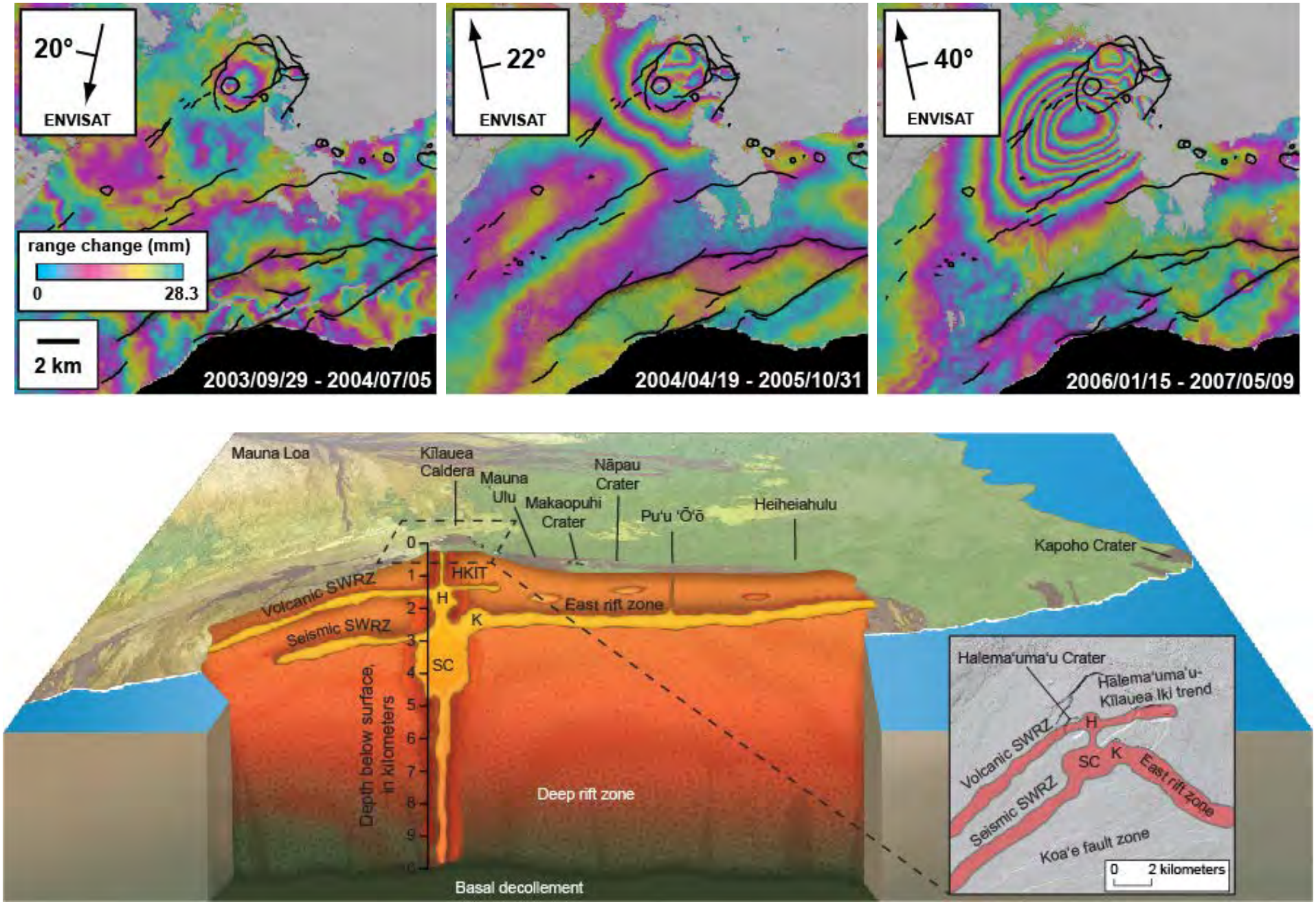


A simple volcanic system
2. Discharging the system
(a. eruptions)

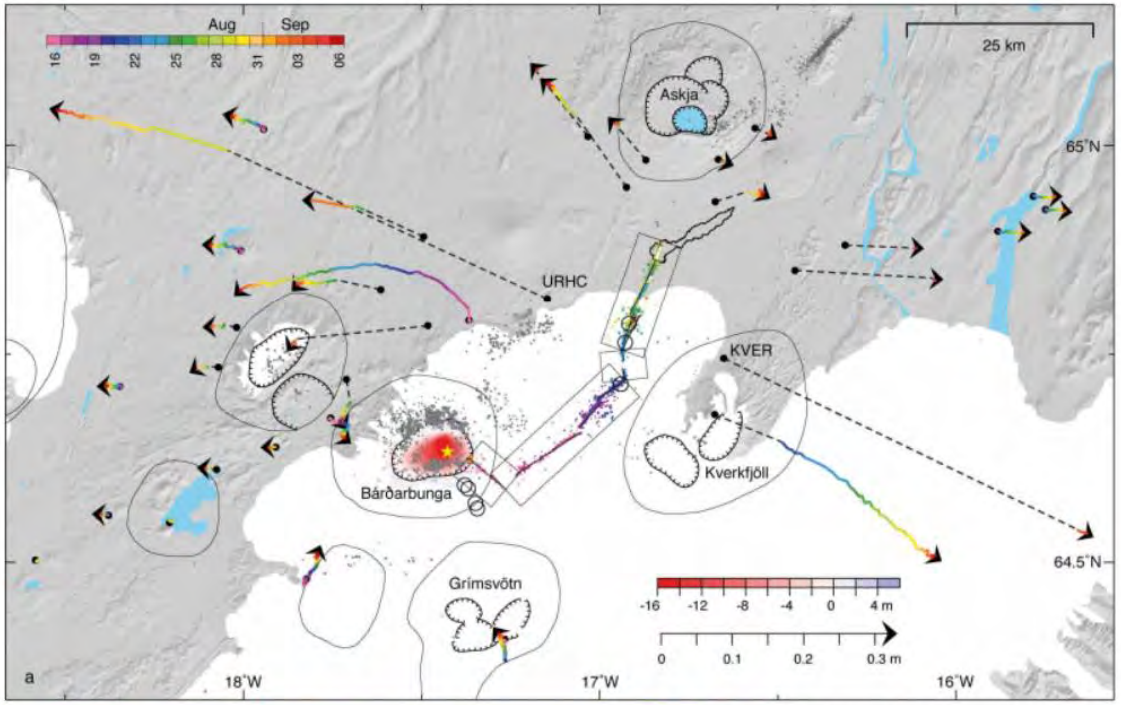


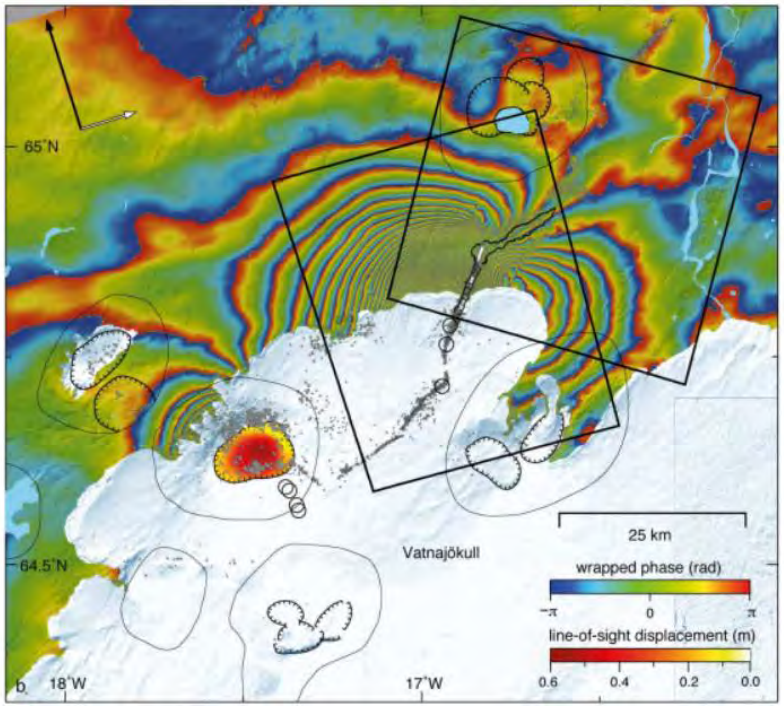
A simple volcanic system
2. Discharging the system
(b. intrusions)

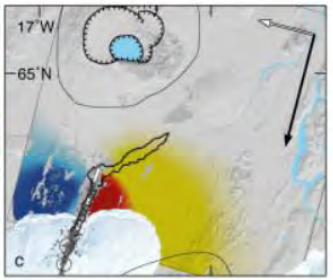


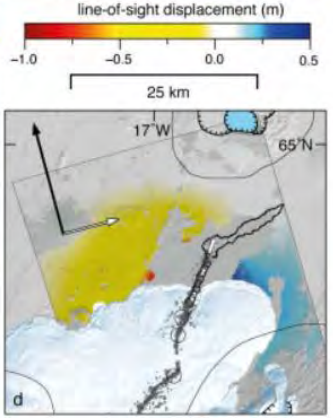


USGS Courtesy Mike Poland, Hawaii Volcano Observatory



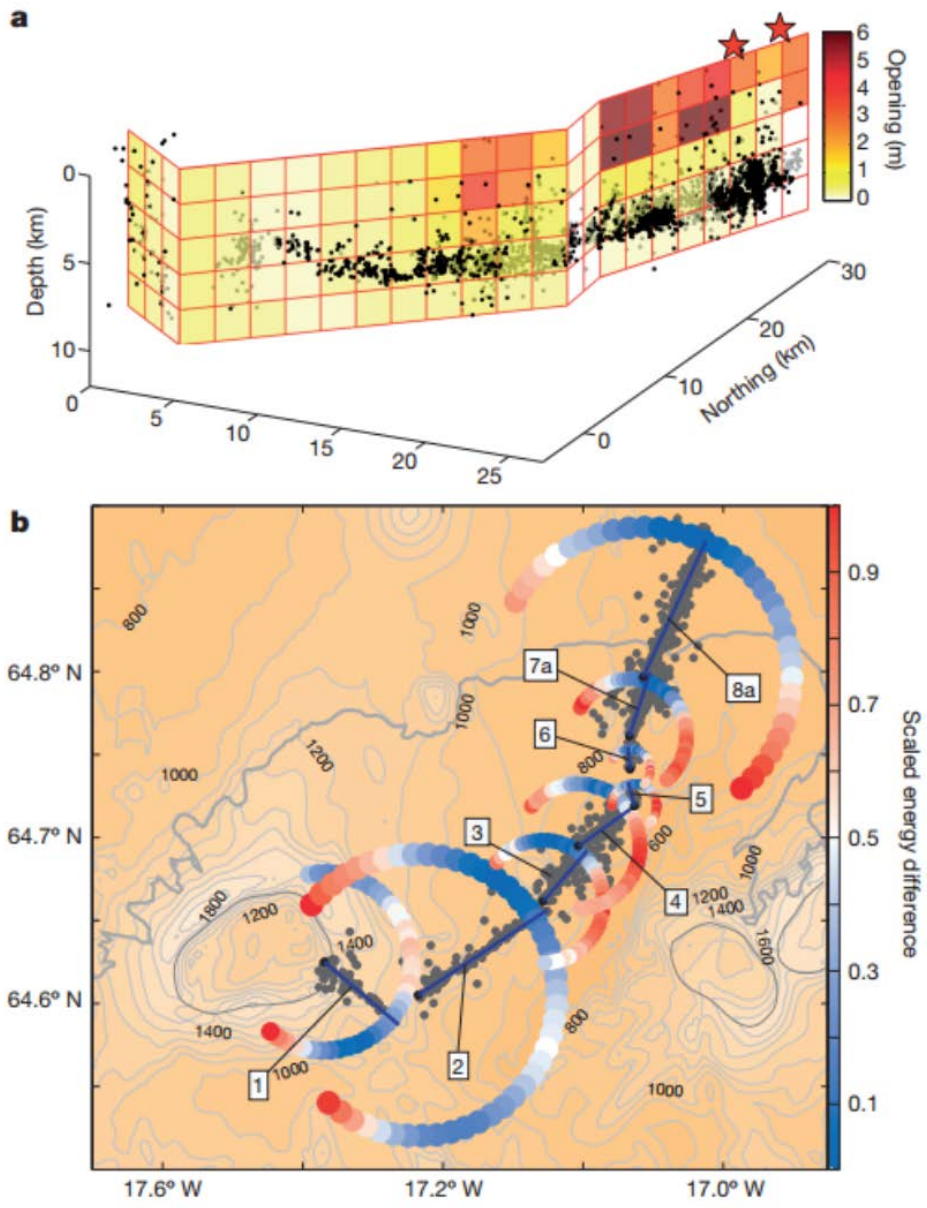






Bardarbunga intrusion and eruption, Iceland 2014-2015

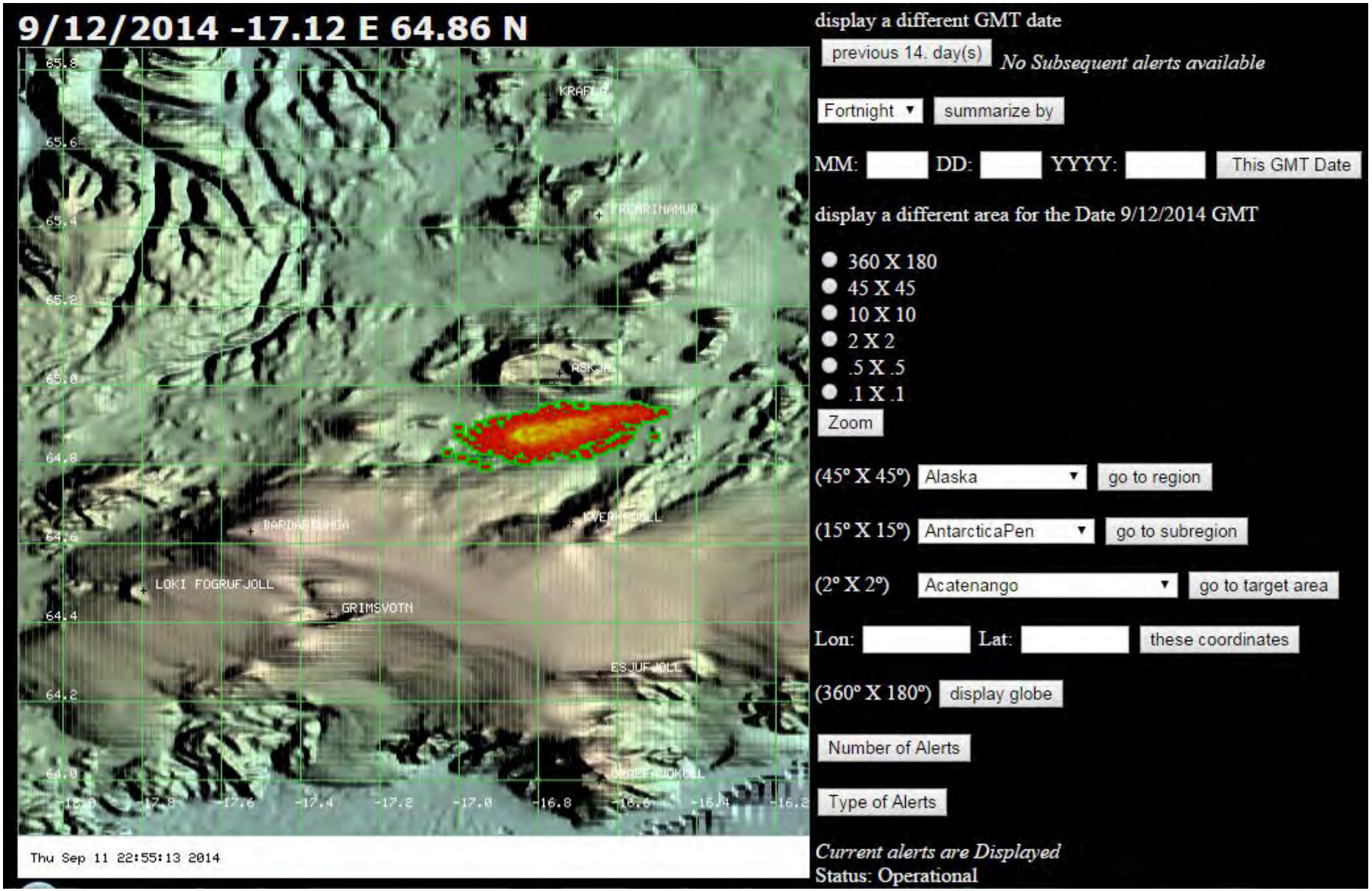
Sigmundsson, Hooper et al., Nature 2014



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/

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

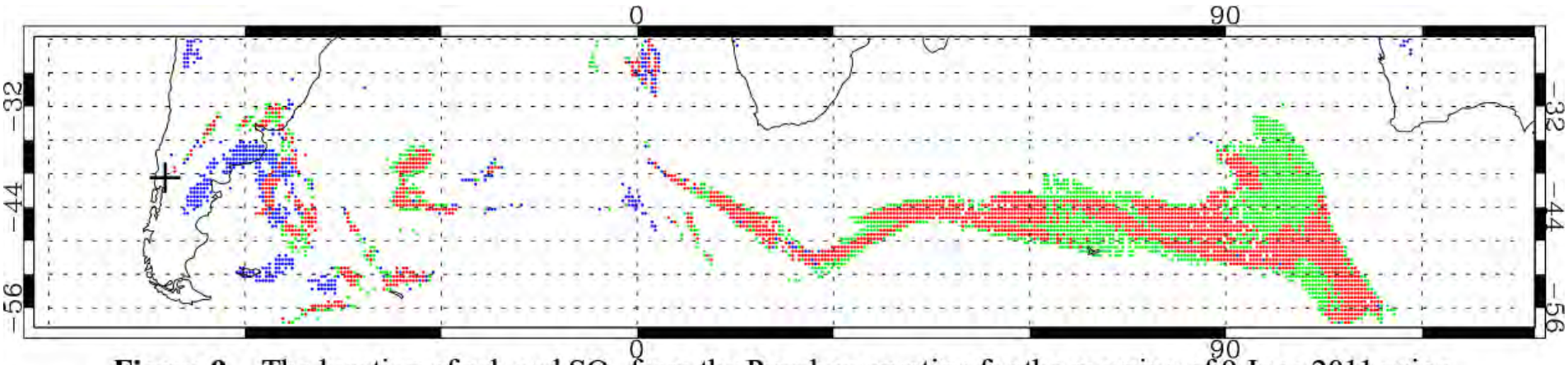
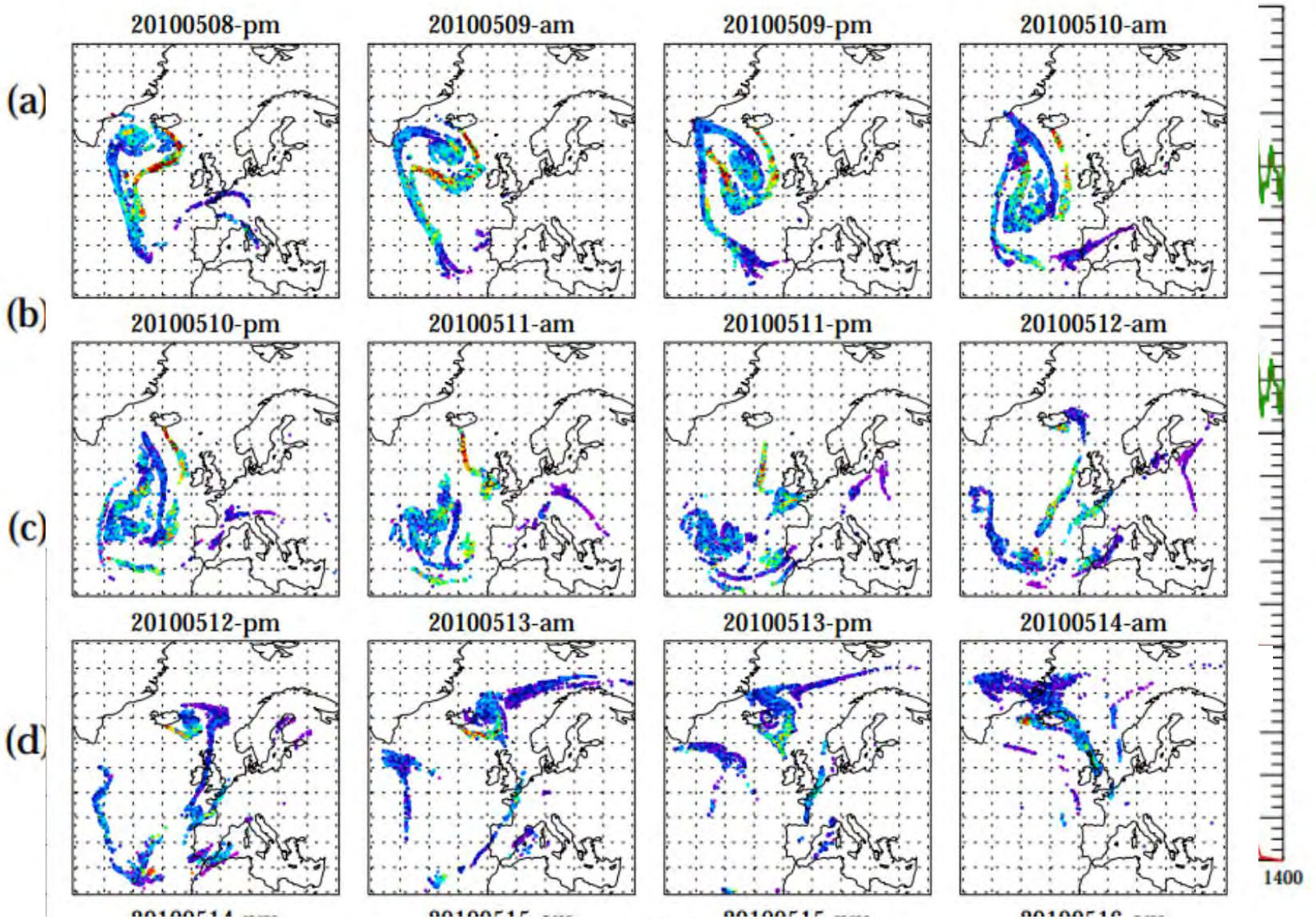


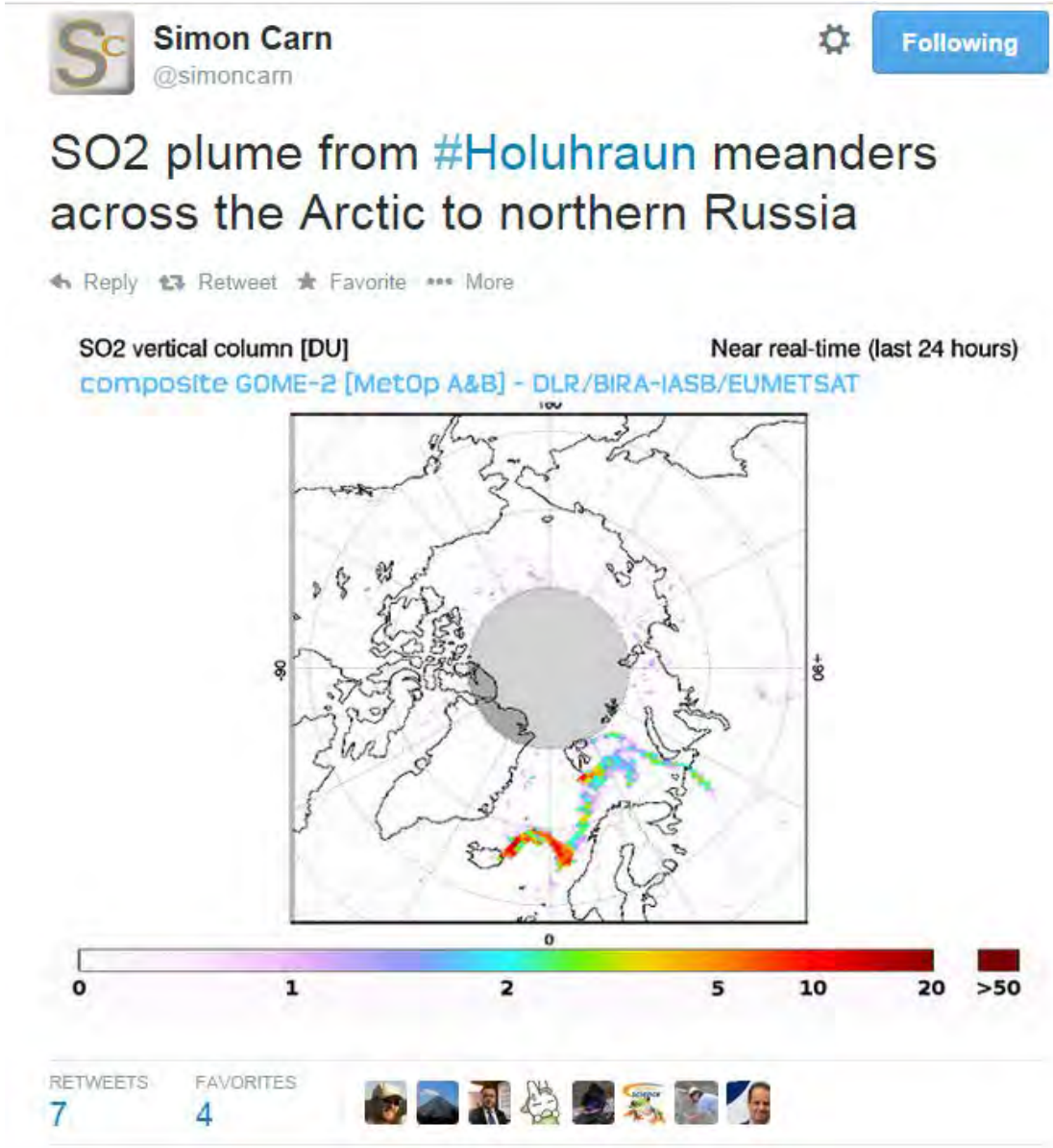
Figure 9. The location of ash and SO_2 from the Puyehue eruption for the morning of 9 June 2011 using the IASI SO_2 and ash flags. The black cross marks the location of the volcano. (red) Both ash and SO_2 are present; (green) Only SO_2 is present; (blue) Only ash is present.

From absorption spectra in the UV

IASI (Infrared)

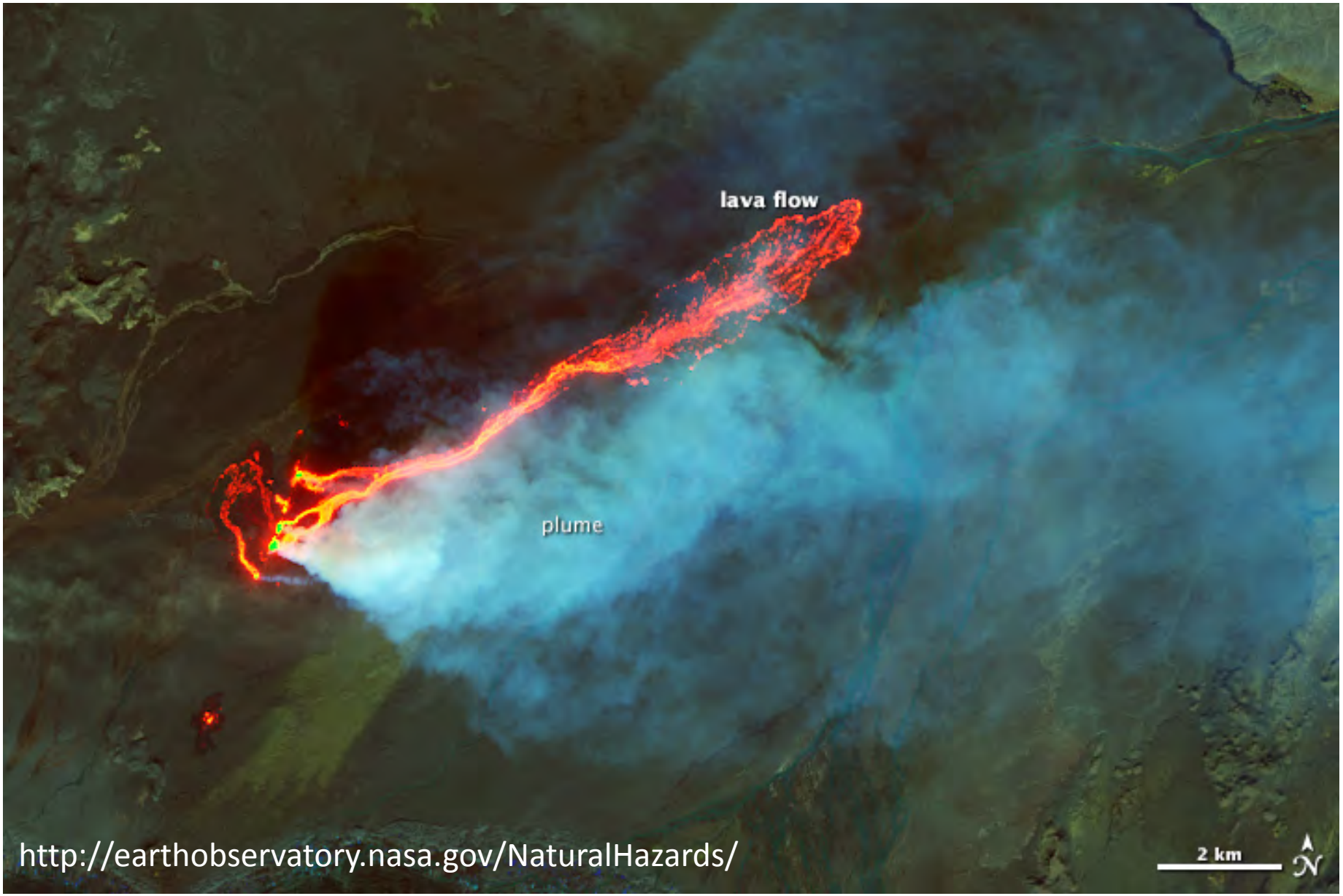


Carboni et al, 2012

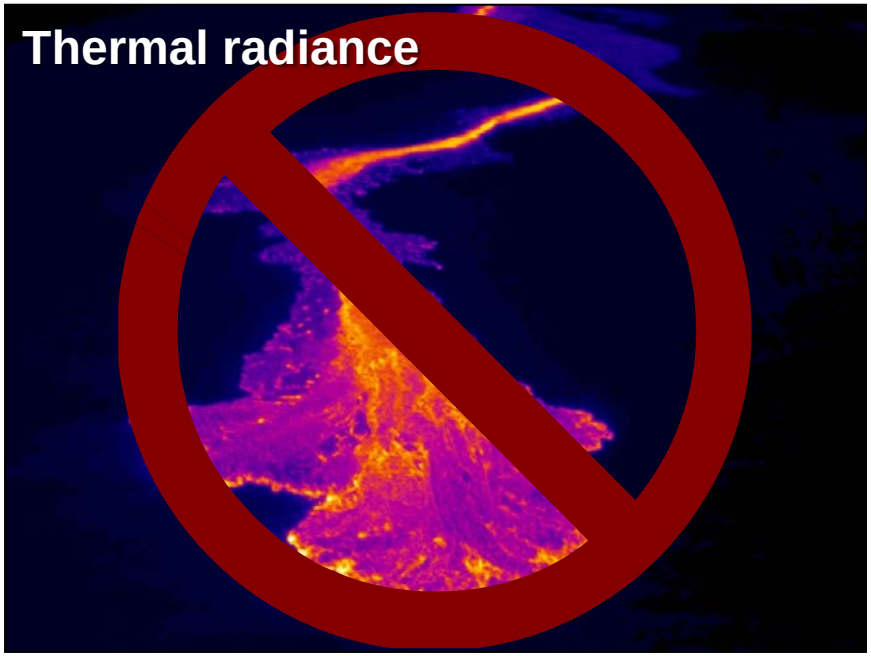


From absorption spectra in the UV

Bardabunga lava from Landsat 8



Q3 How much has erupted?

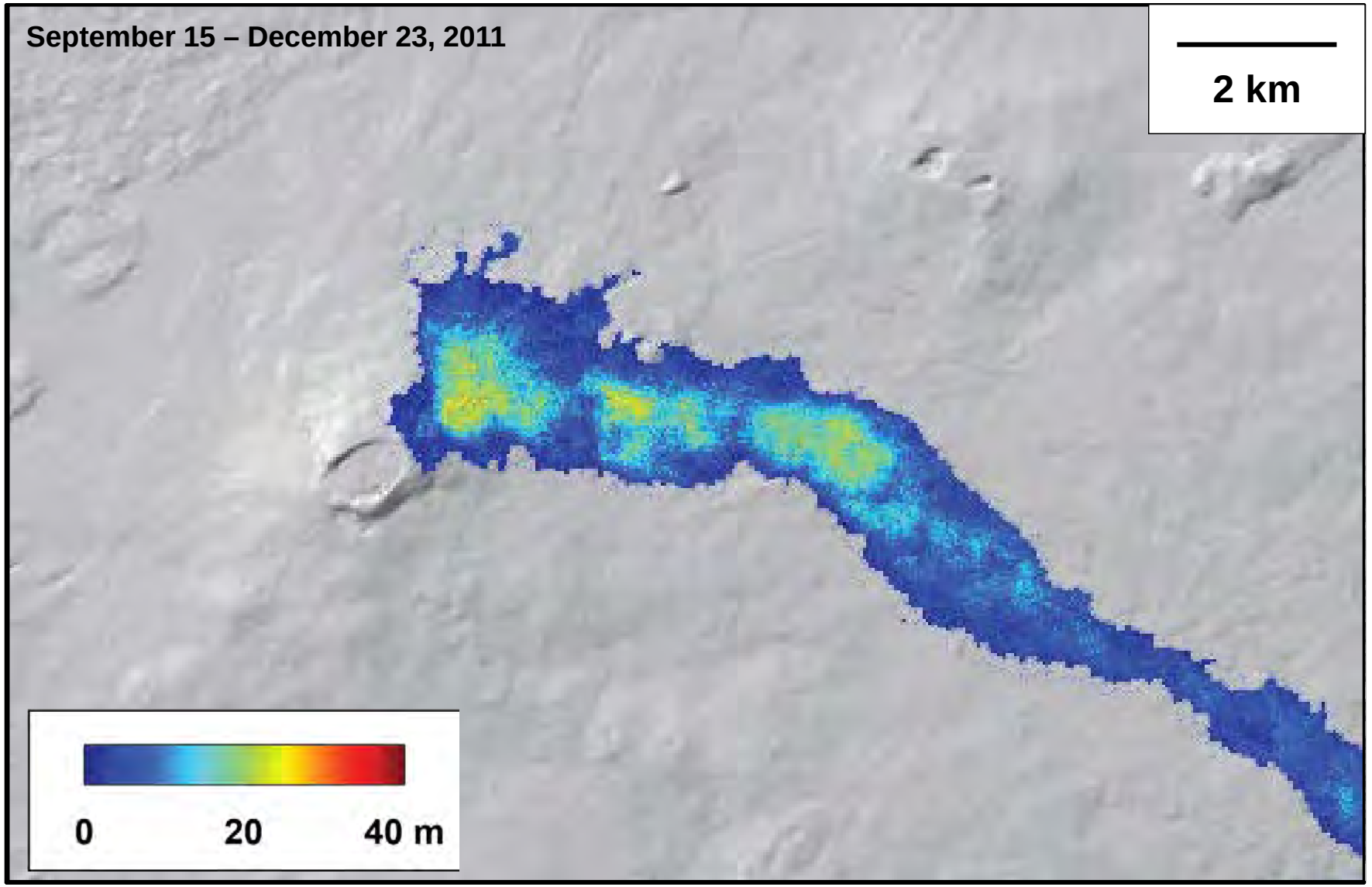


USGS Courtesy Mike Poland, Hawaii Volcano Observatory

TanDEM-X

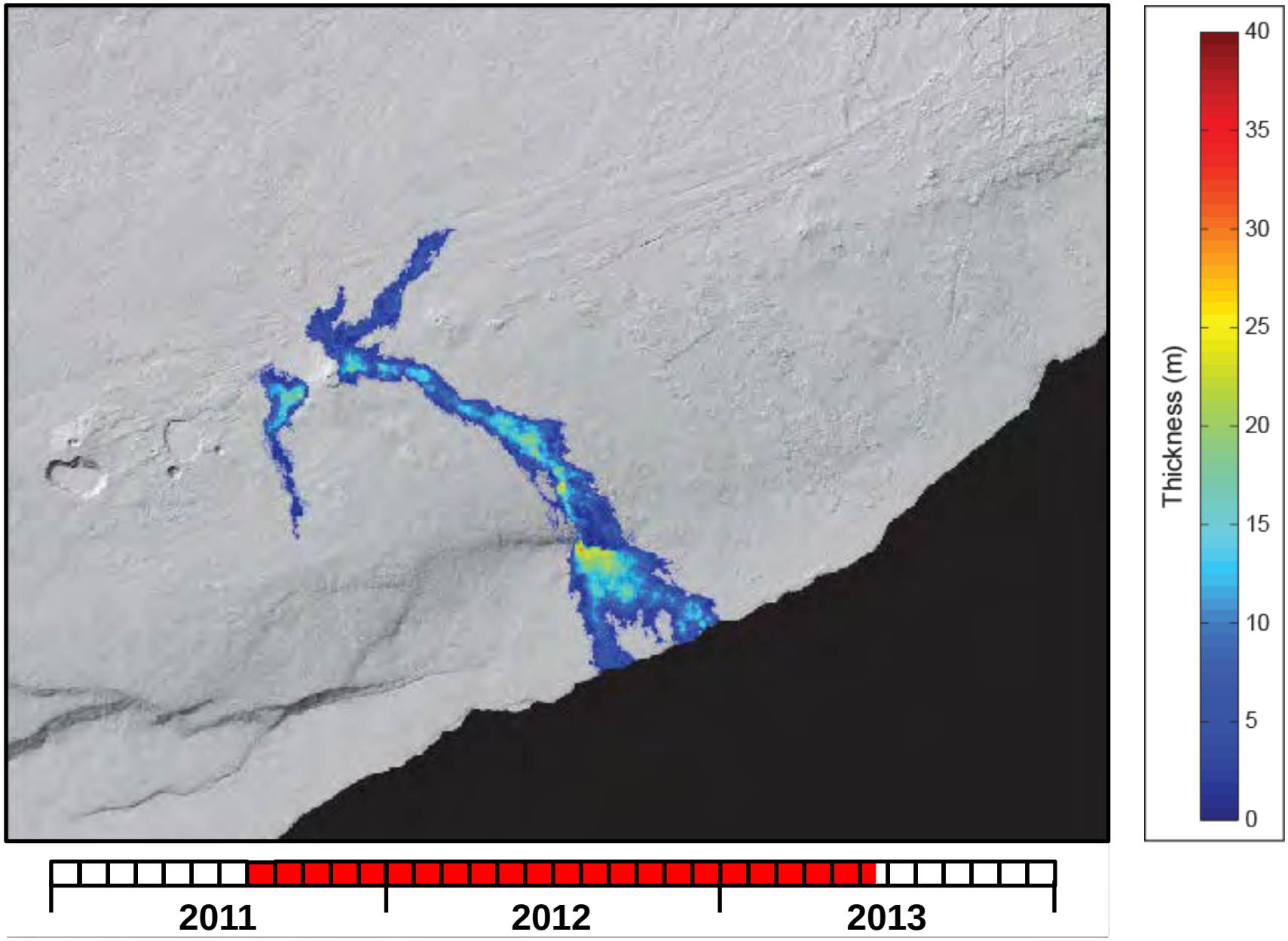
USGS

Three for the price of one

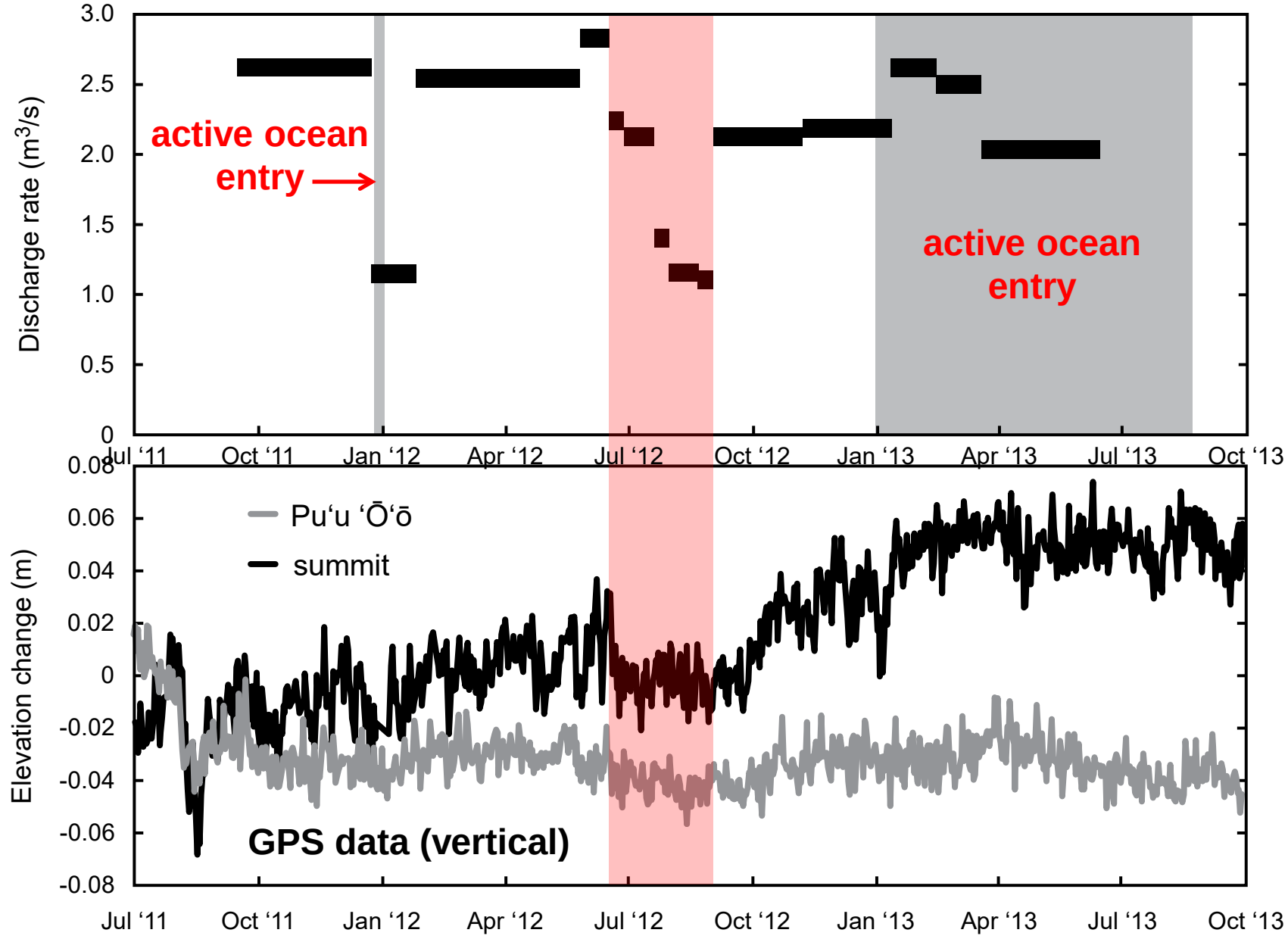


Courtesy Mike Poland, Hawaii Volcano Observatory

Deformation



USGS Courtesy Mike Poland, Hawaii Volcano Observatory

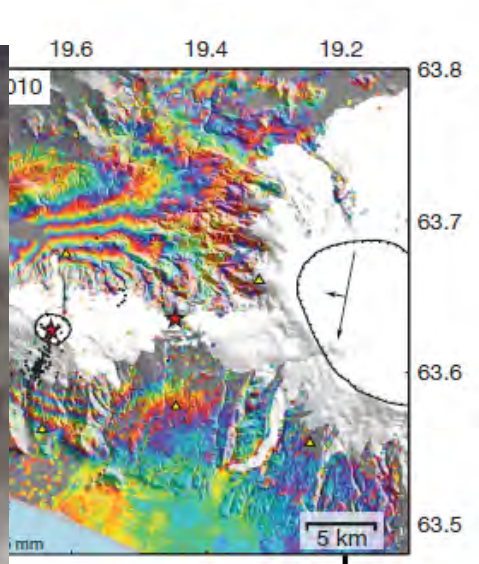


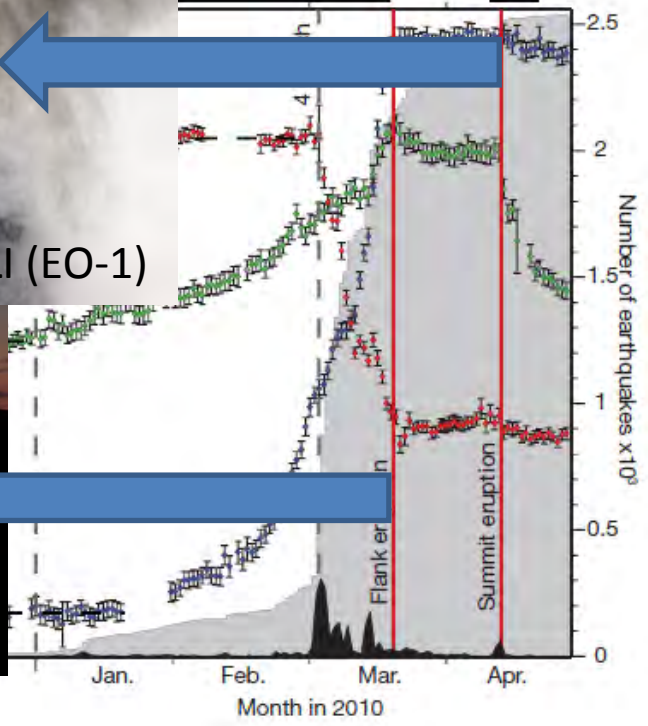
USGS Courtesy Mike Poland, Hawaii Volcano Observatory

Q4 What will happen next?

Eyjafjallajökull 20

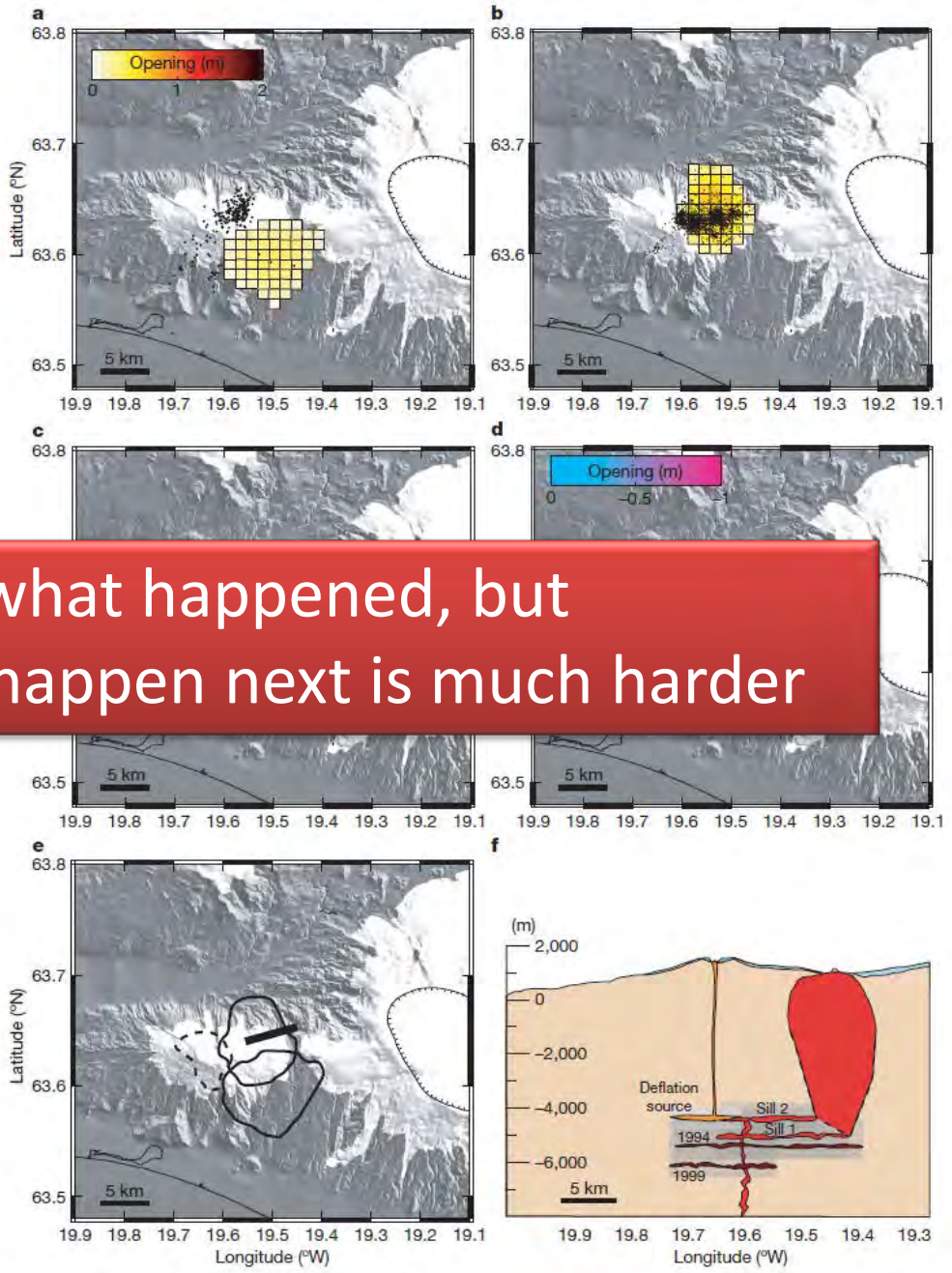
NASA ALI (EO-1)





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

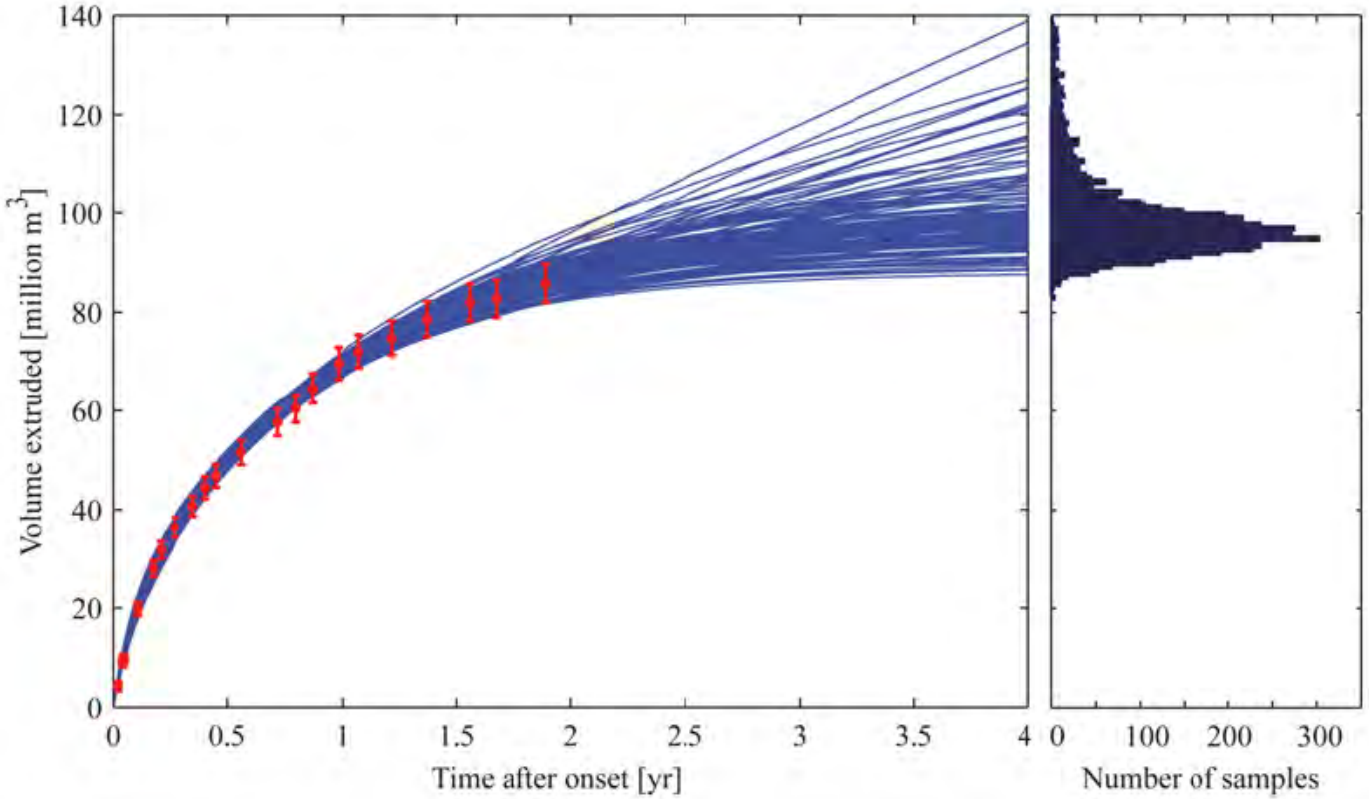
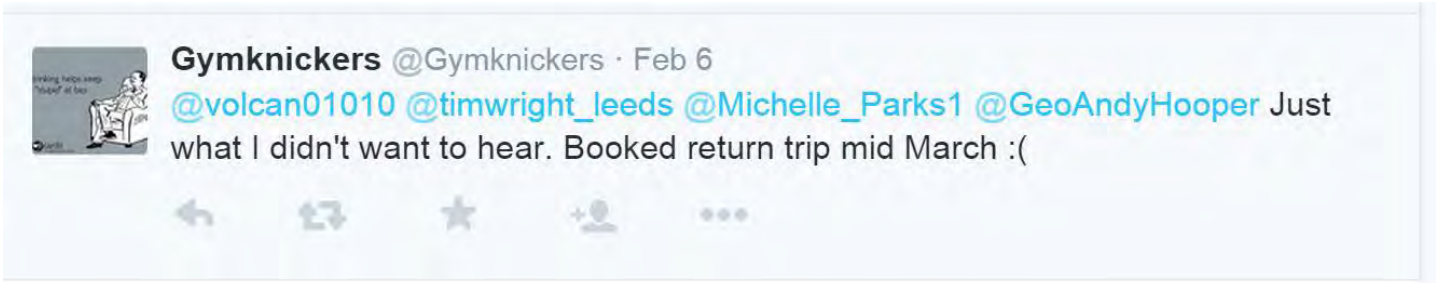


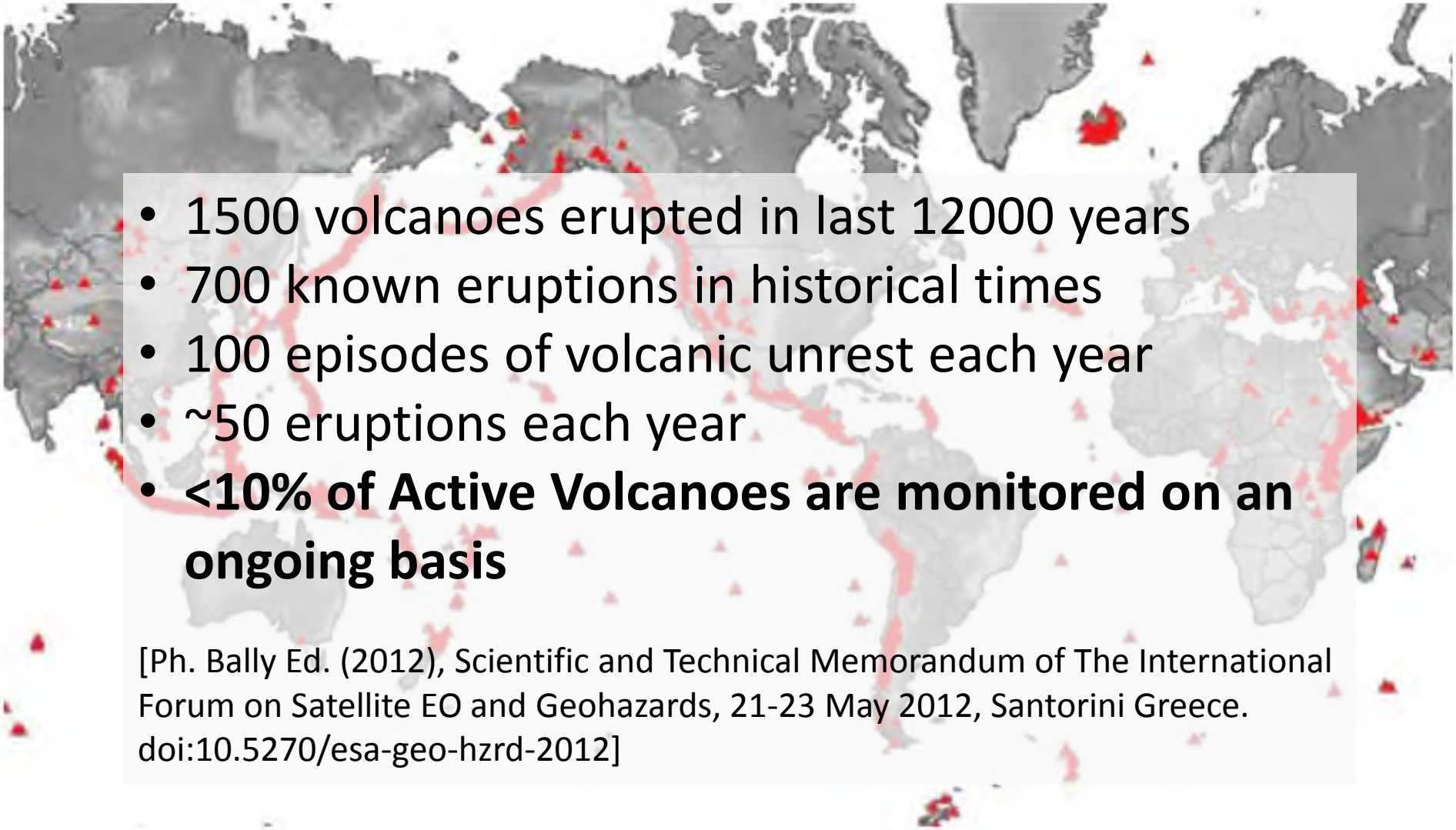
Fig. 15. Example of MCMC forecast using data from Mount St Helens for 2 years following eruption onset. Extruded volume is shown with 1σ error bars (red in online version). MCMC procedure yields a large set of model estimates consistent with the data (GPS data not shown). The model parameters were then 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



Actual eruption end date: 27 February 2015

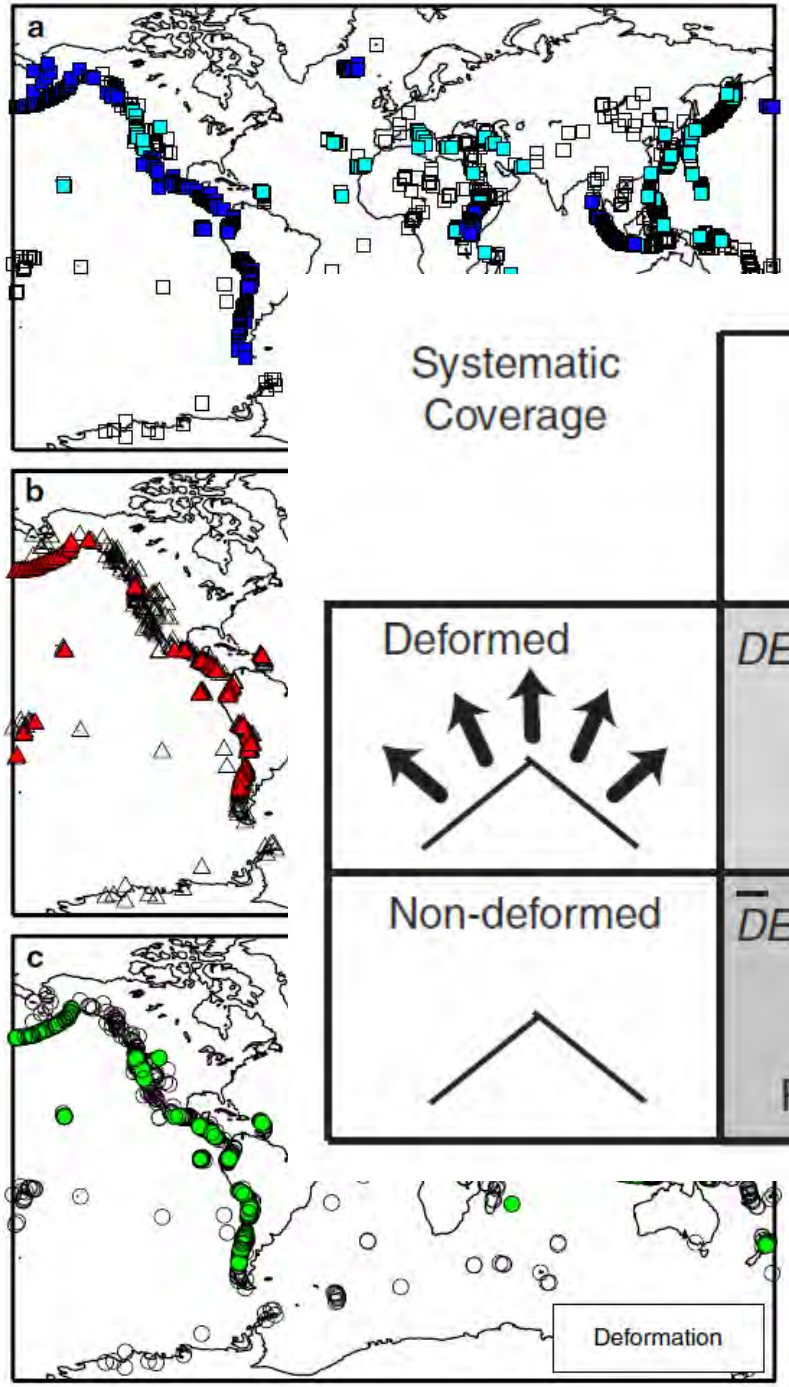
Q5 What is the probability of a volcano erupting?



- 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?



Systematic Coverage	Erupted	Non-Erupted
Deformed	DE 25 True positive	$D\overline{E}$ 29 False positive
Non-deformed	$\overline{D}E$ 9 False negative	$\overline{D}\,\overline{E}$ 135 True negative

Biggs et al., Nature Communications 2014

Part b: Witnessing the birth of a new ocean? The 2005-2010 Afar Rifting Episode

Tim Wright
University of Leeds, UK
Plus collaborators from the Afar Rift Consortium

Afar Rift Consortium

THE ROYAL SOCIETY

NATURAL ENVIRONMENT RESEARCH COUNCIL

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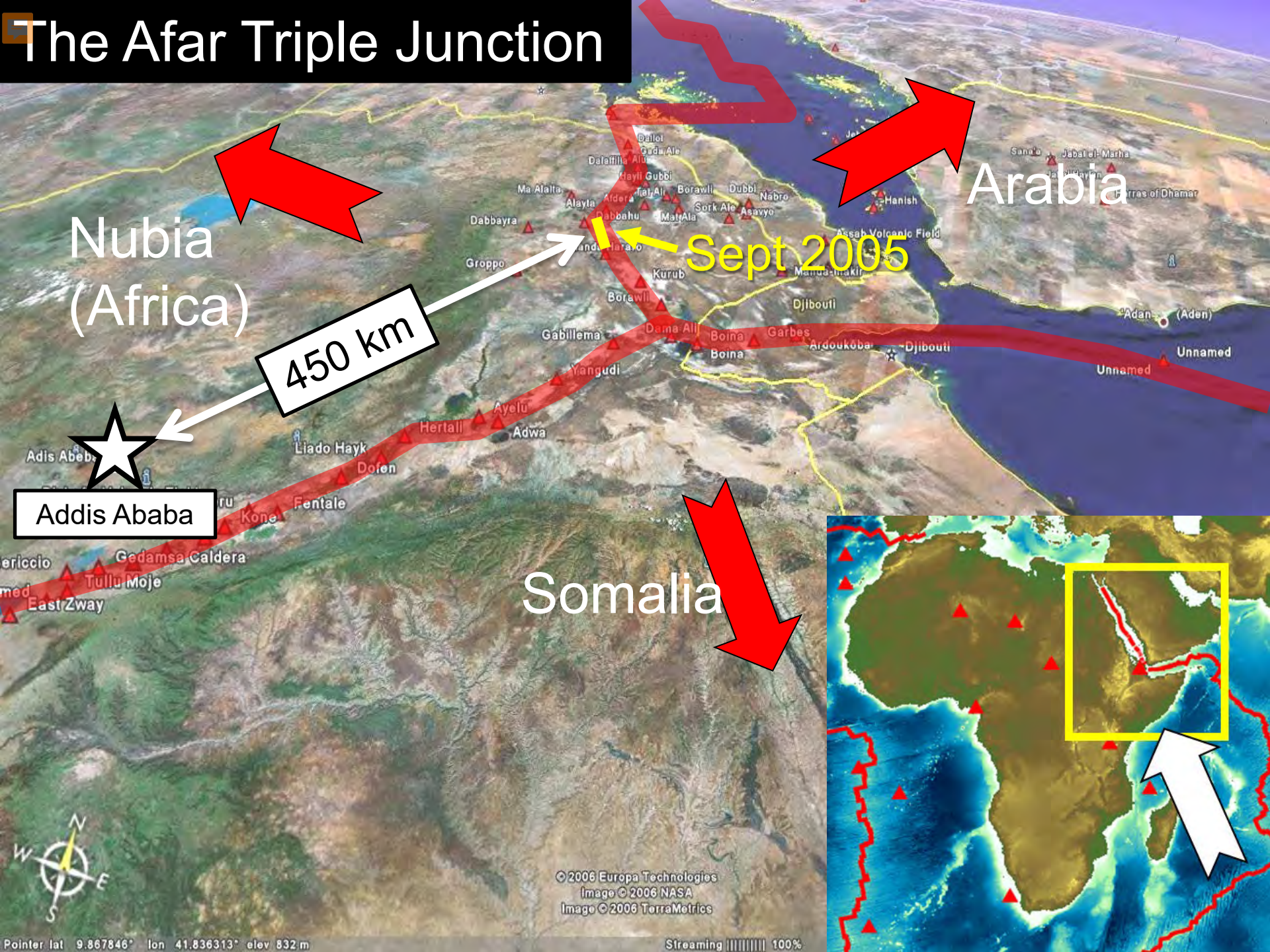
INSTITUTE OF GEOPHYSICS & TECTONICS
UNIVERSITY OF LEEDS

UNAVCO


Anthony Philpotts, October 2005


Photograph: Ebinger, 2005
ON EW & NS
Power & Heat are off
Atalay Ayele , Addis Ababa University


24/9, 2005 vs 14/9, 2005.
Geophysical Observatory,
Addis Ababa University
Photograph: Ebinger, 2005
Pelikan


The Afar Triple Junction
Nubia
(Africa)
Arabia
Somalia
Sept 2005
450 km
Addis Ababa
Adis Abeba
Liado Hayk
Hertali
Ayelu
Adwa
Dofen
Fentale
Kone
Gedamsa Caldera
Tullu Moje
East Zway
Yangudi
Gabillema
Dama Ali
Boina
Garbes
Ardoukoba
Djibouti
Borawli
Kurub
Groppo
Dabbayra
Ma'alalta
Alayla
Dubbi
Nabro
Sork Ale
Asavyo
Hanish
Assab Volcanic Field
Adan
(Aden)
Unnamed
Unnamed
© 2006 Europa Technologies
Image © 2006 NASA
Image © 2006 TerraMetrics
Pointer lat 9.867846° lon 41.836313° elev 832 m
Streaming 100%

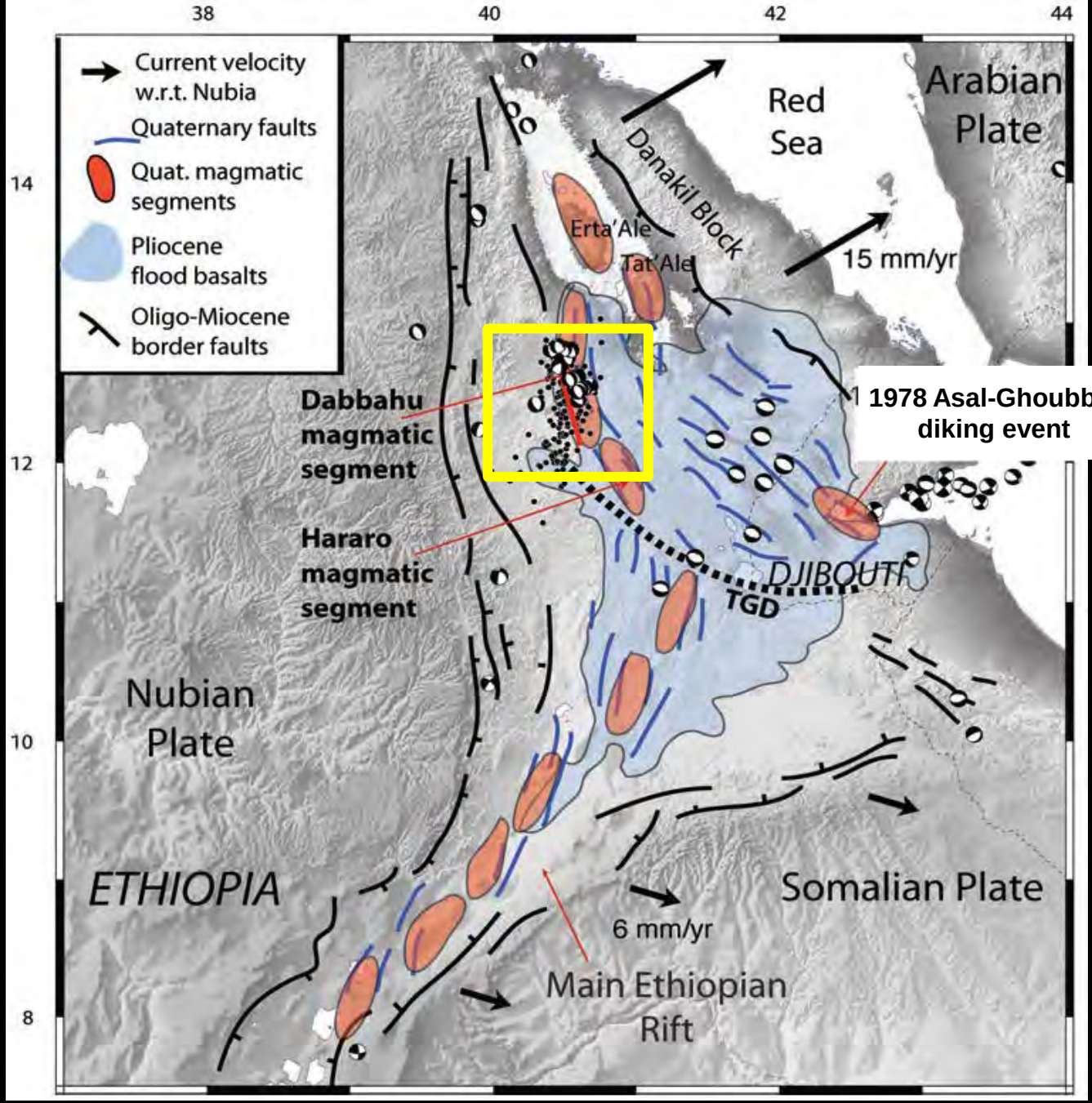

26 September 2005, Da'Ure eruption
Liz Baker, March 2006


Anthony Philpotts, October 2005

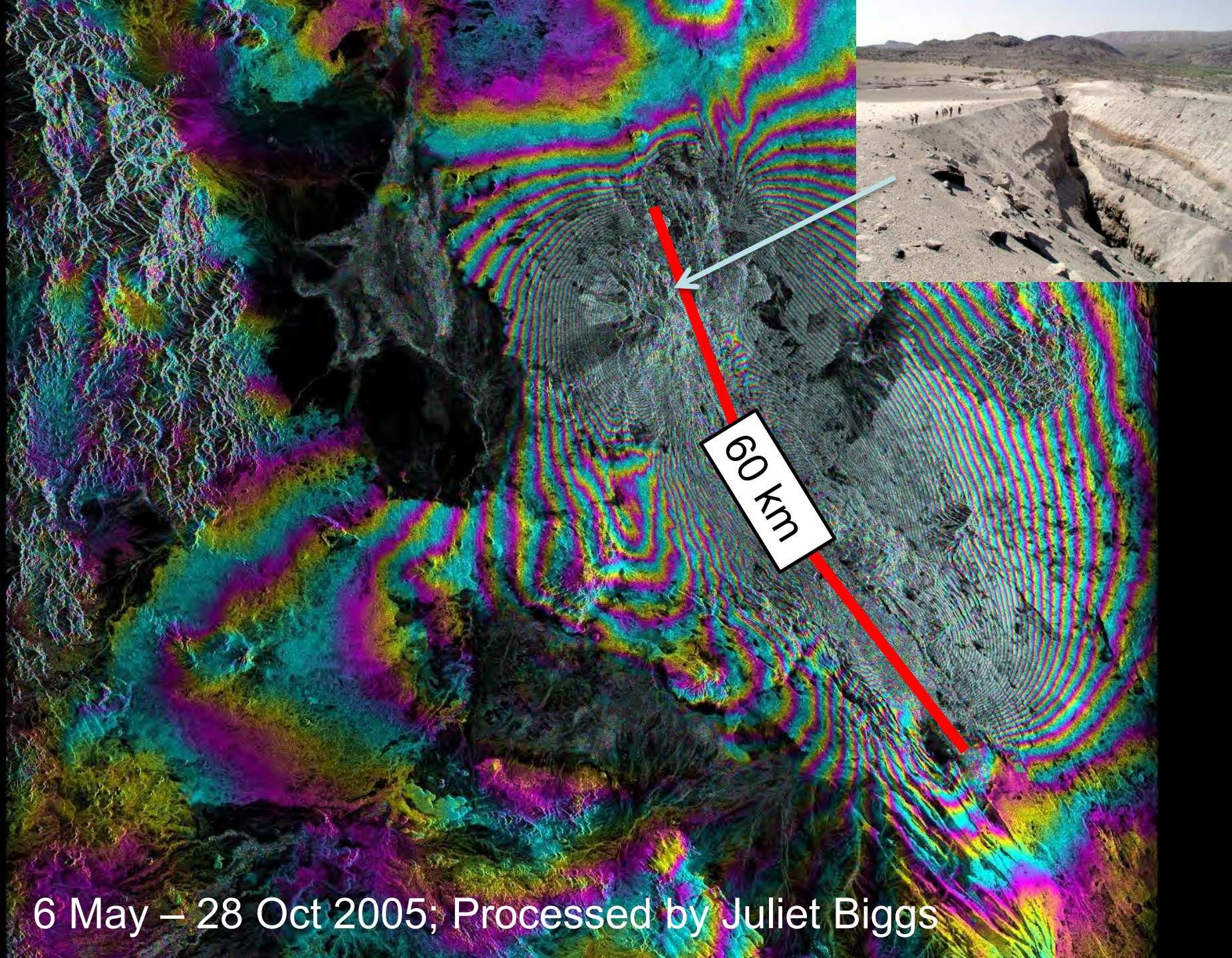

Liz Baker, March 2006

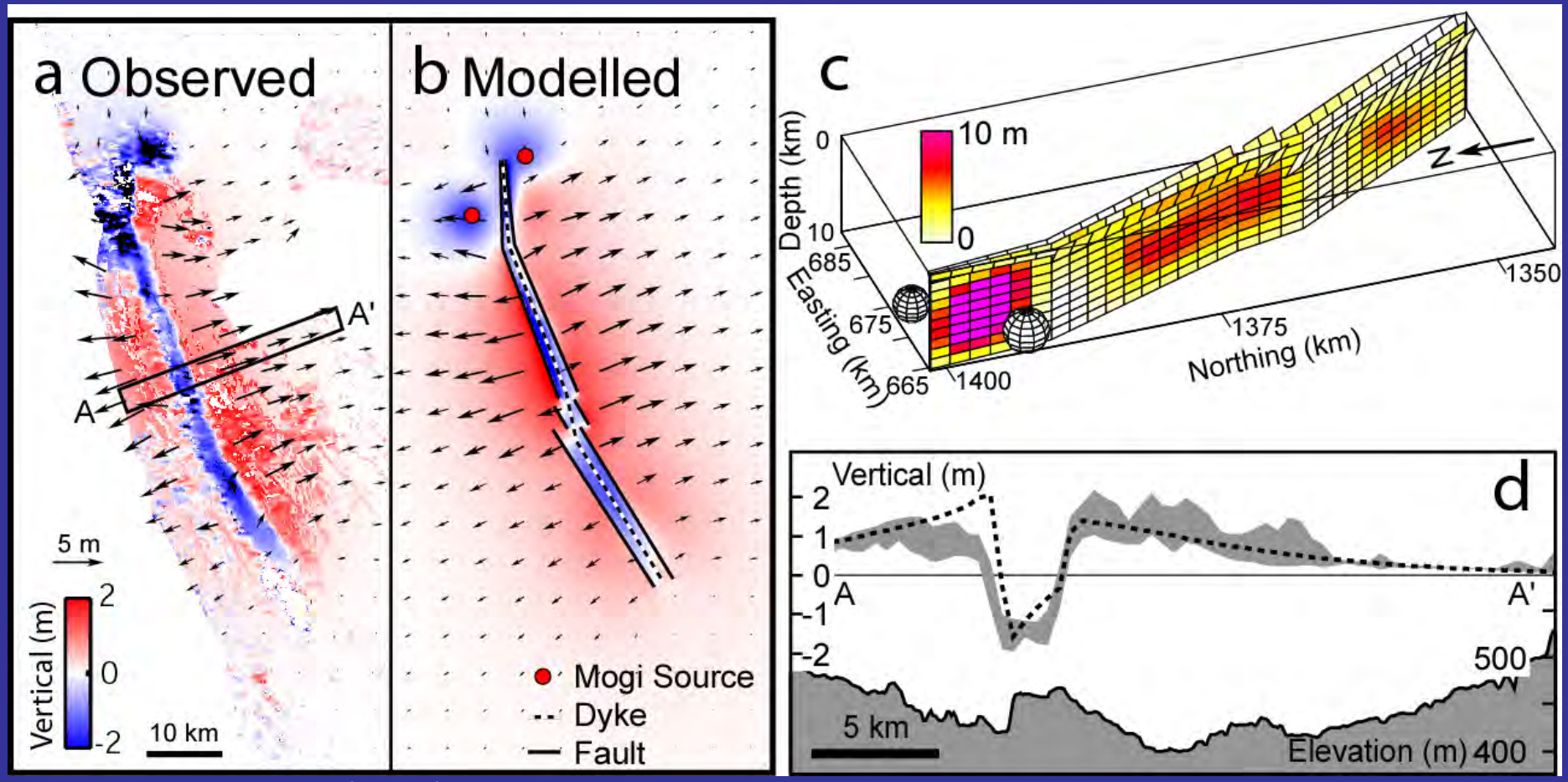

James Hammond, Jan 2006


Liz Baker, March 2006



From Ebinger et al., GJI 2008


60 km
6 May – 28 Oct 2005; Processed by Juliet Biggs

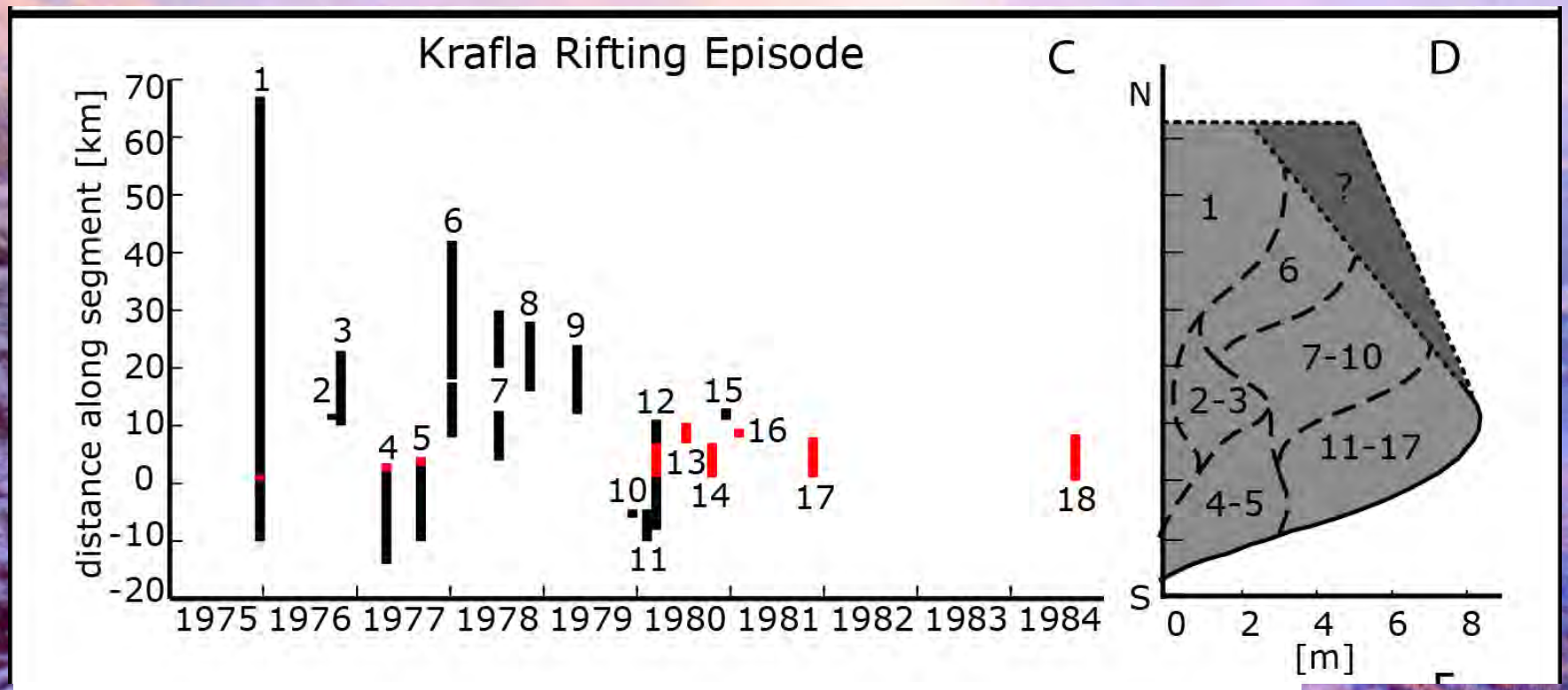


Wright et al., Nature (2006)

- ~2.5 km^3 magma intruded along dyke (Mt St Helens 1980 1.2 km^3); 1 tonne of rock for every human on the planet.
- ~0.5 km^3 sourced from Dabbahu and Gabho volcanoes at North.
- Rest probably fed from deeper chamber under Ado' Ale at segment centre.

Eastern Flank (courtesy J. Rowland – see Rowland et al., GJI 2007)

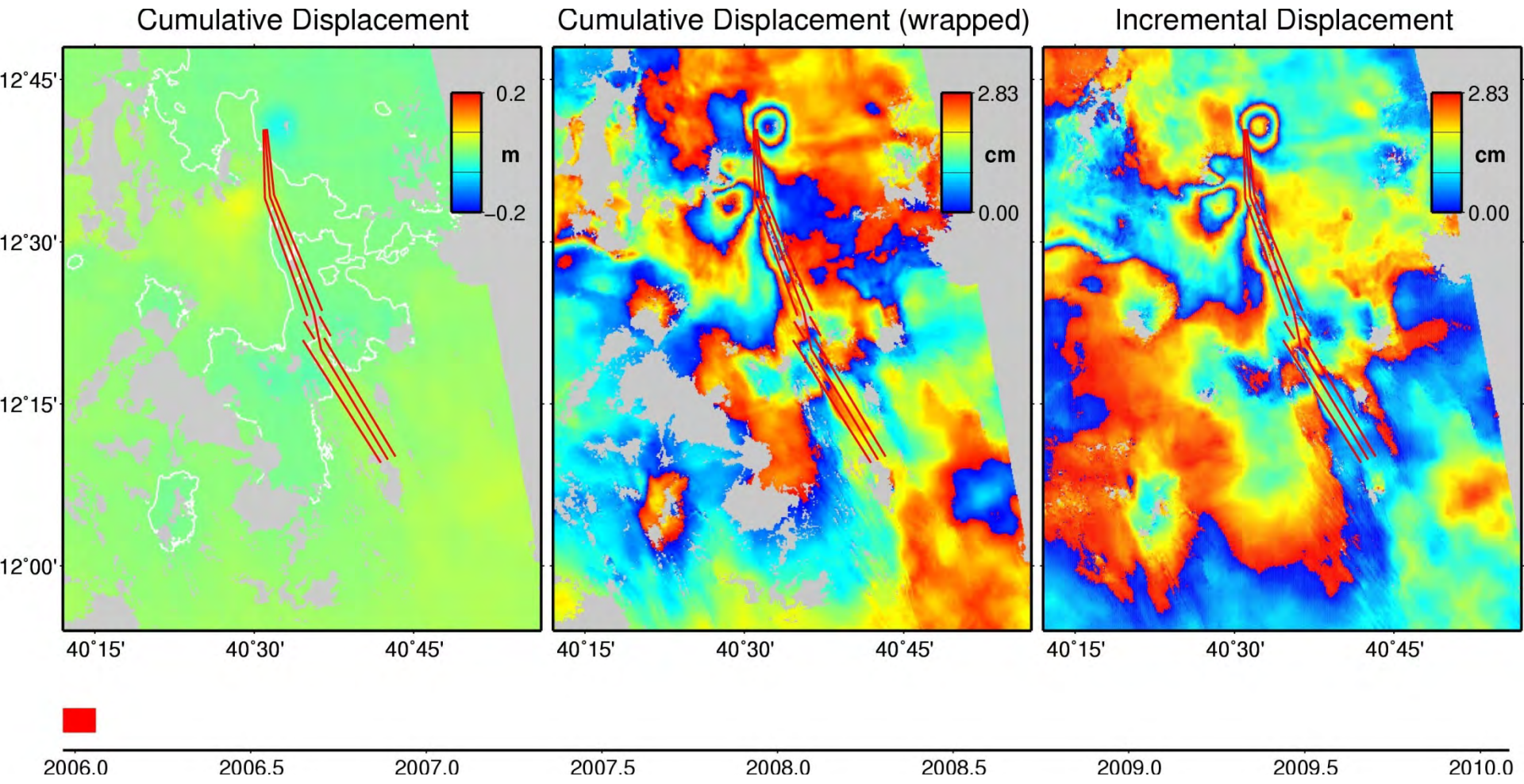
The Krafla rifting episode (Iceland) 1975-1984



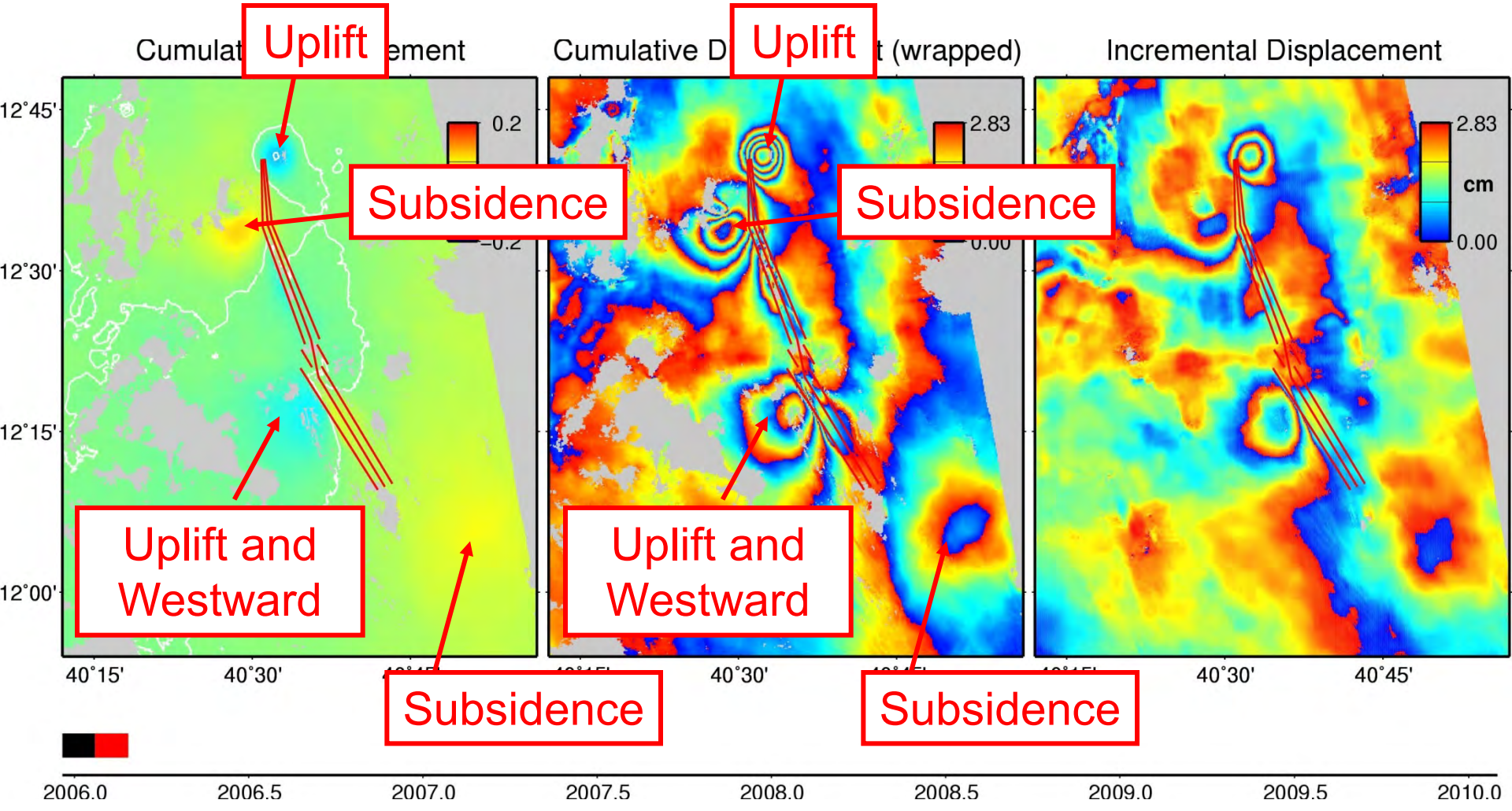
Wright, Sigmundsson et al., Nature Geosci., 2012

Thorarinsson September 8, 1977

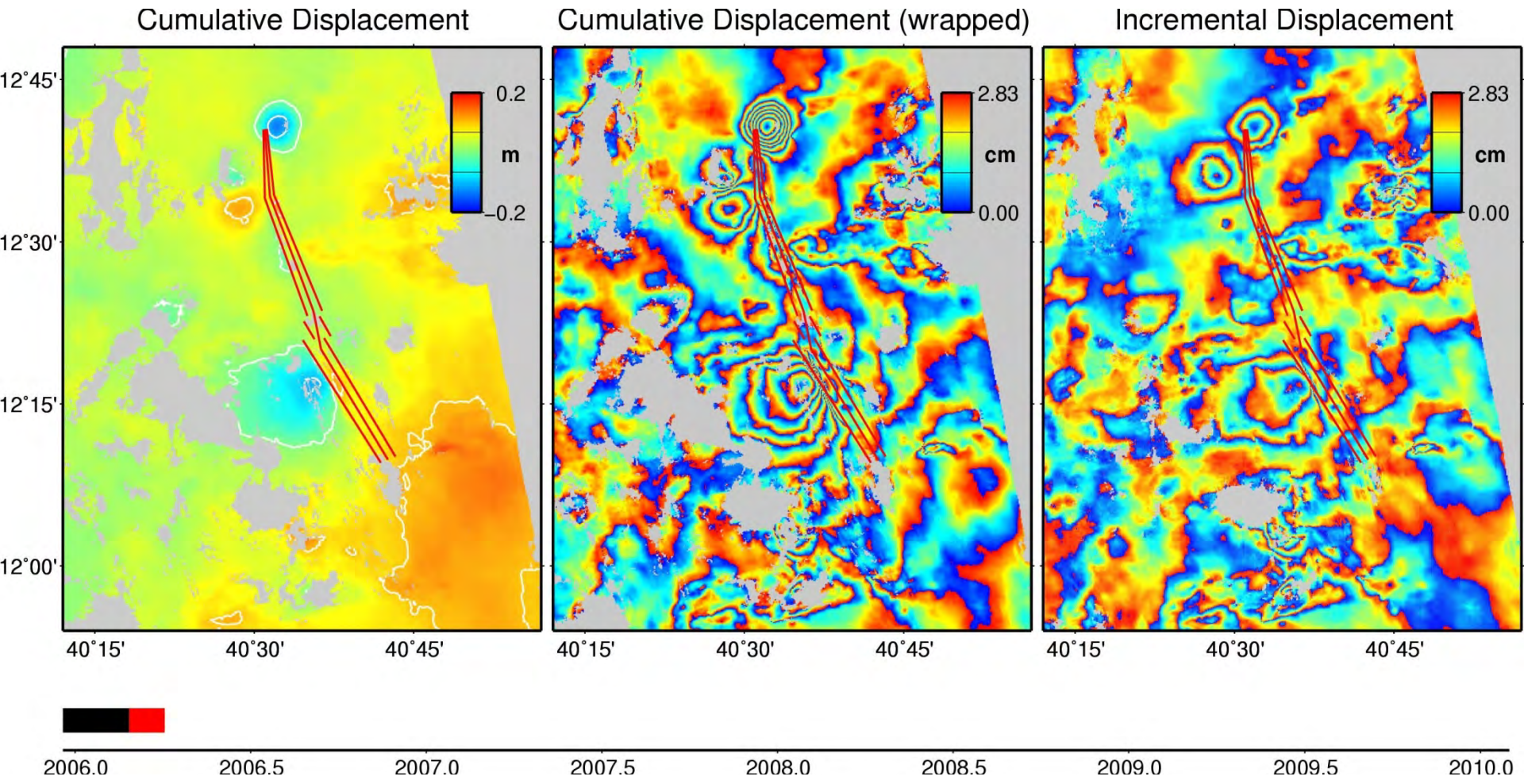
Post-intrusion deformation – Track 300



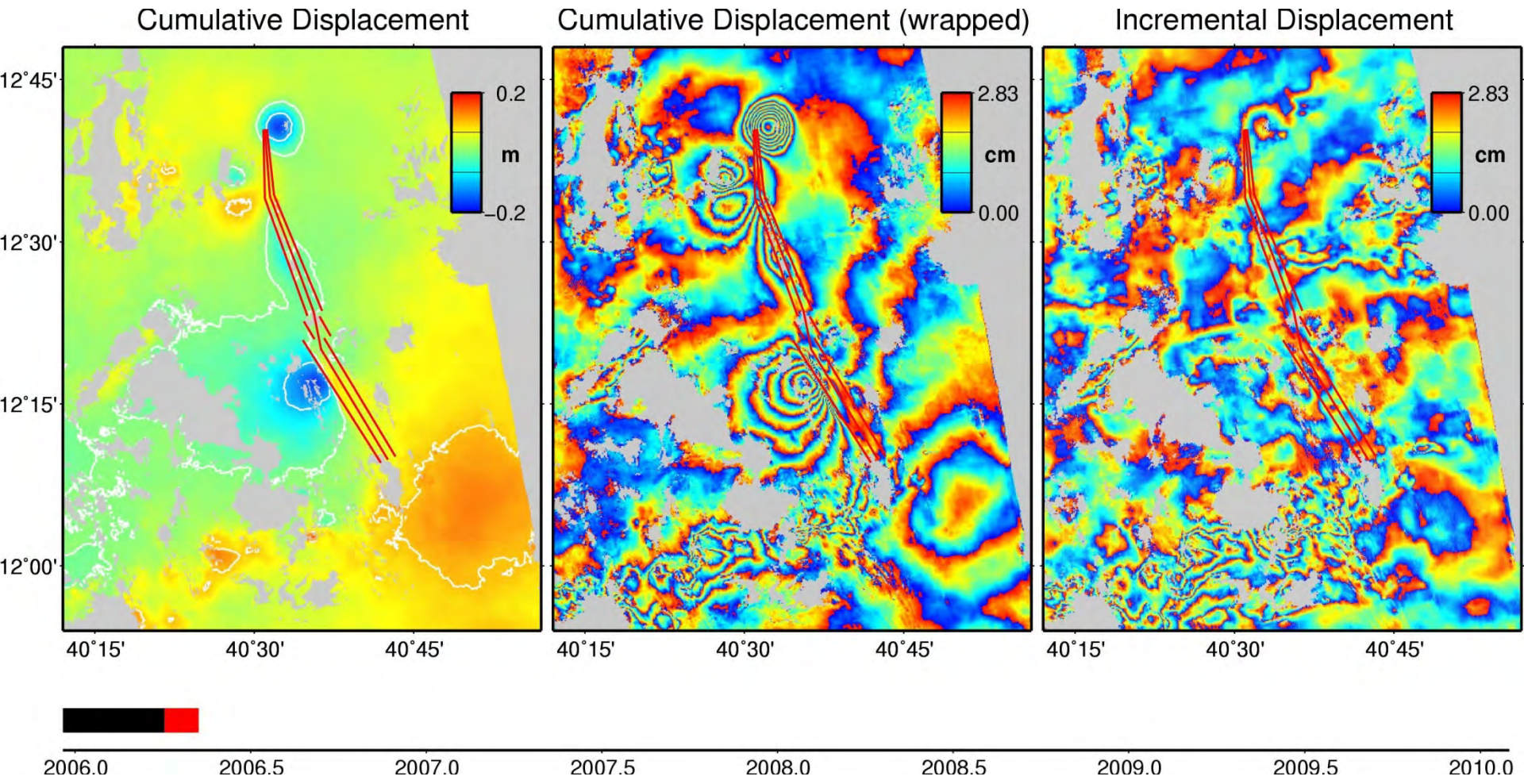
Post-intrusion deformation – Track 300



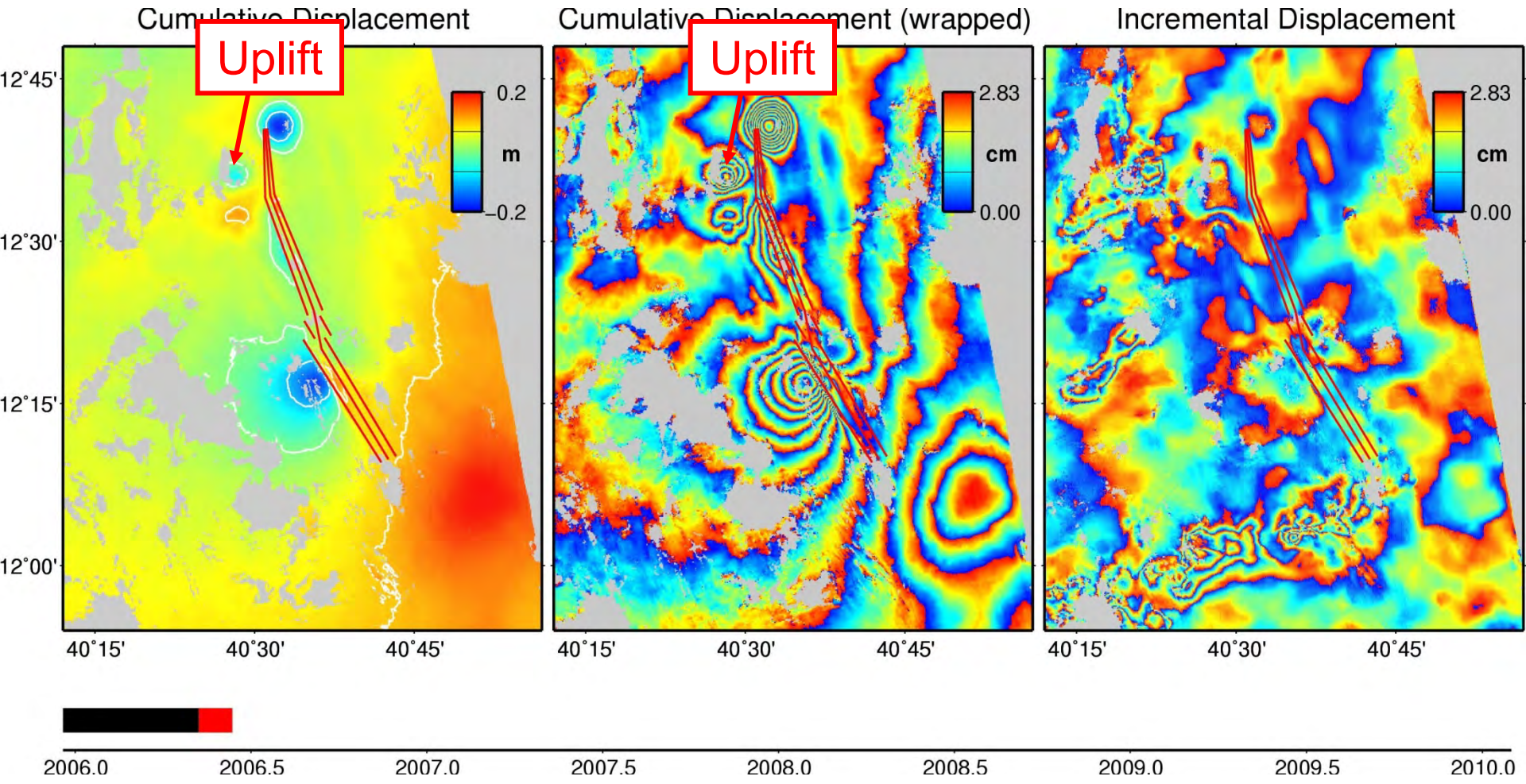
Post-intrusion deformation – Track 300



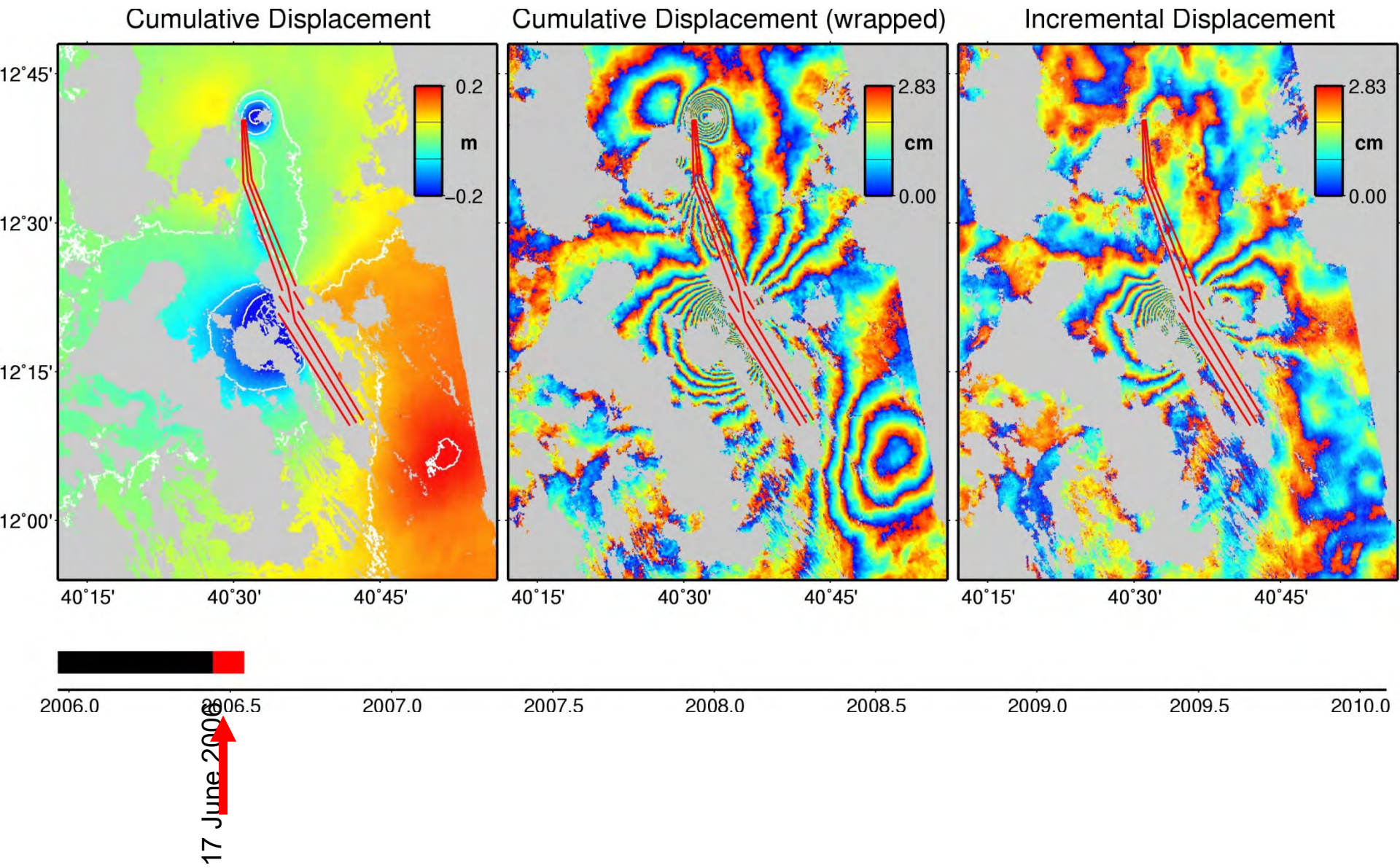
Post-intrusion deformation – Track 300



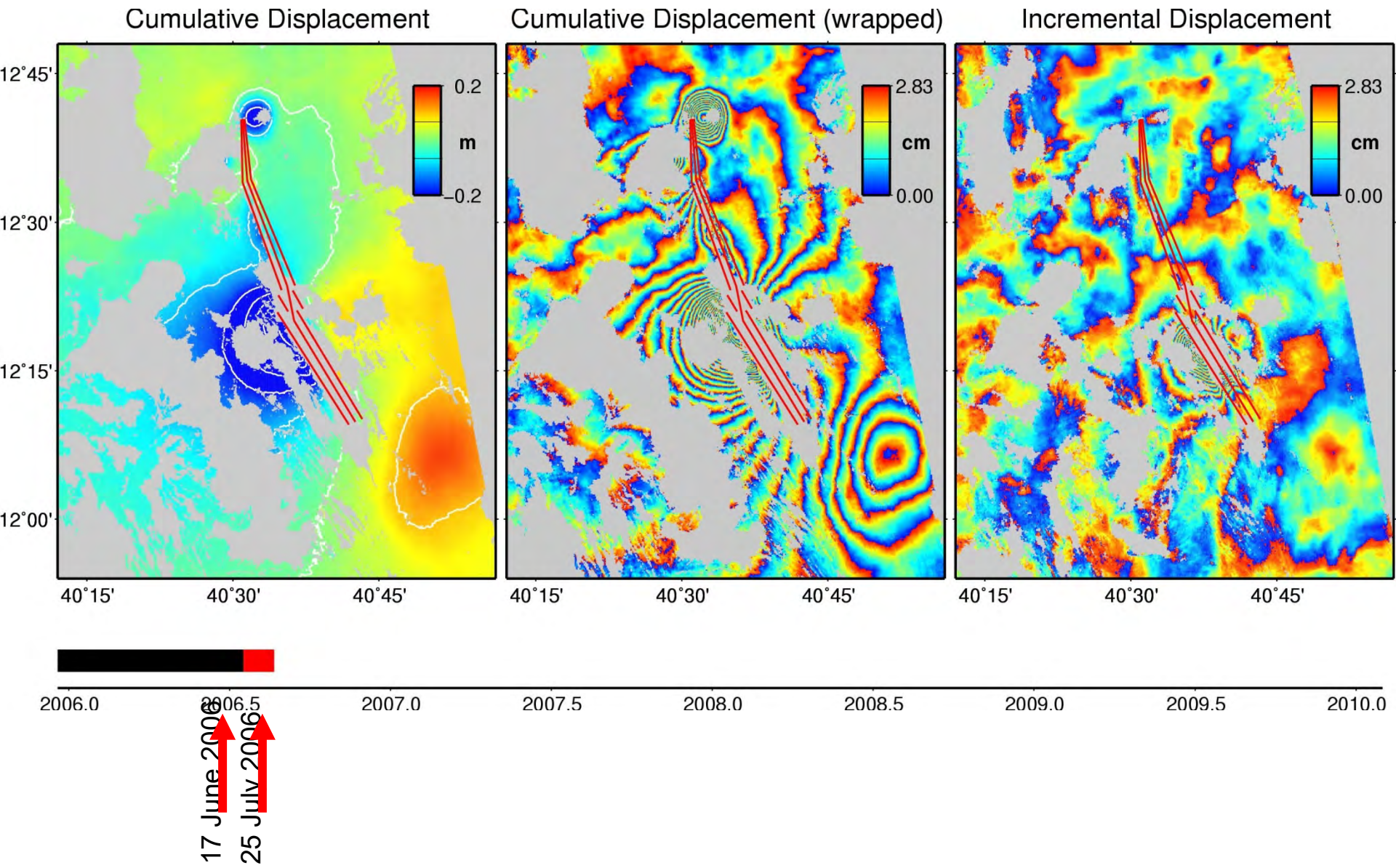
Post-intrusion deformation – Track 300



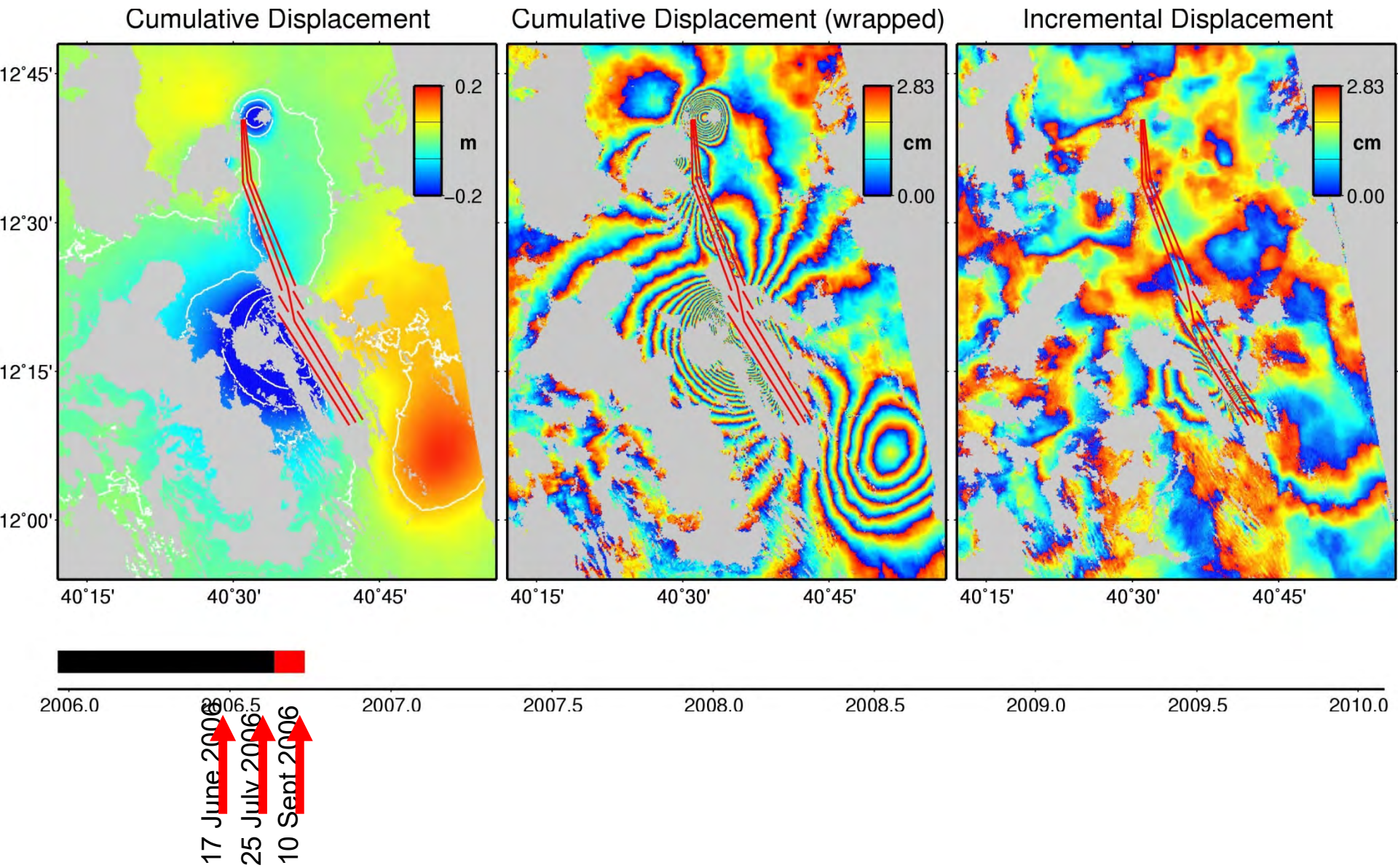
Post-intrusion deformation – Track 300



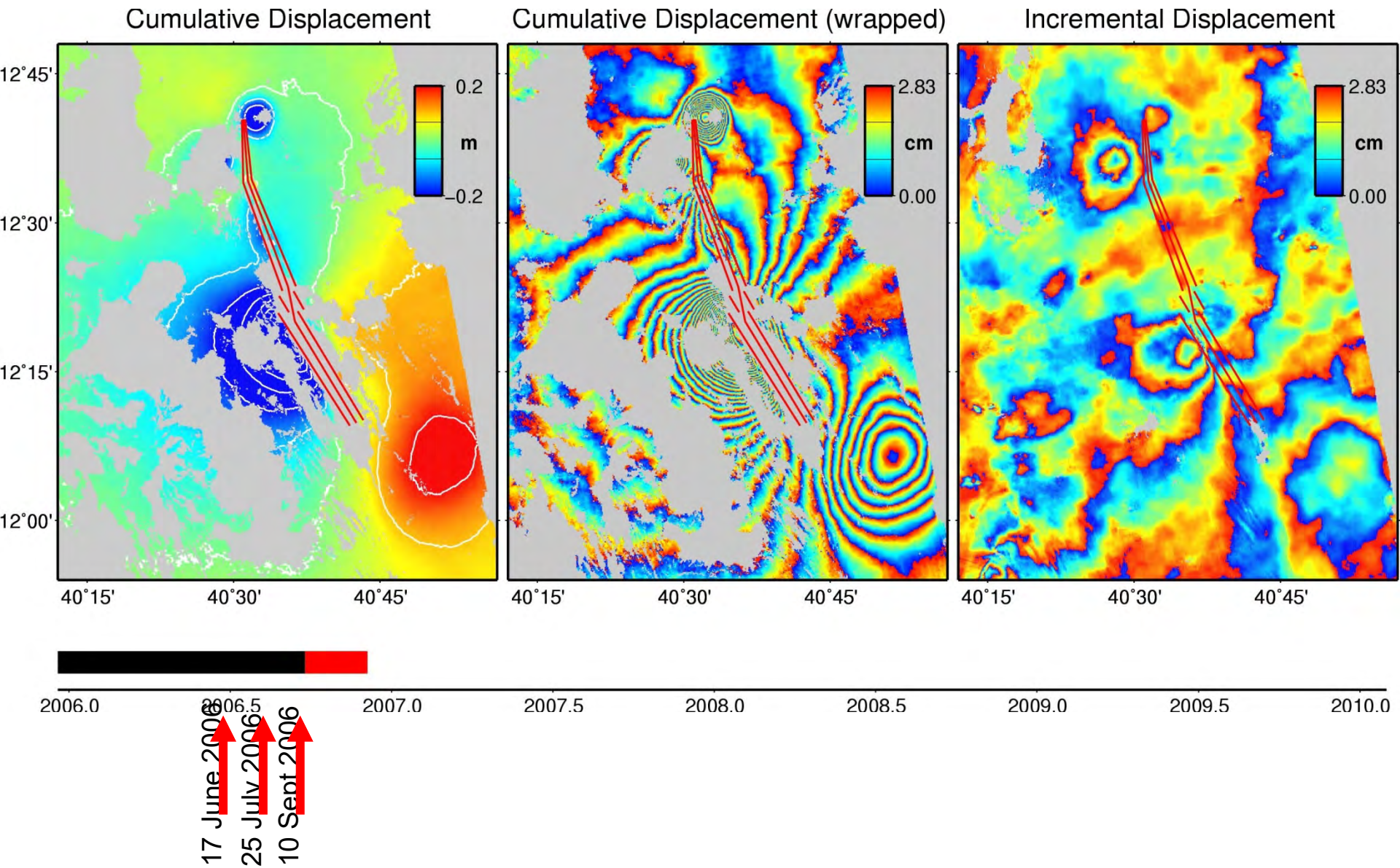
Post-intrusion deformation – Track 300



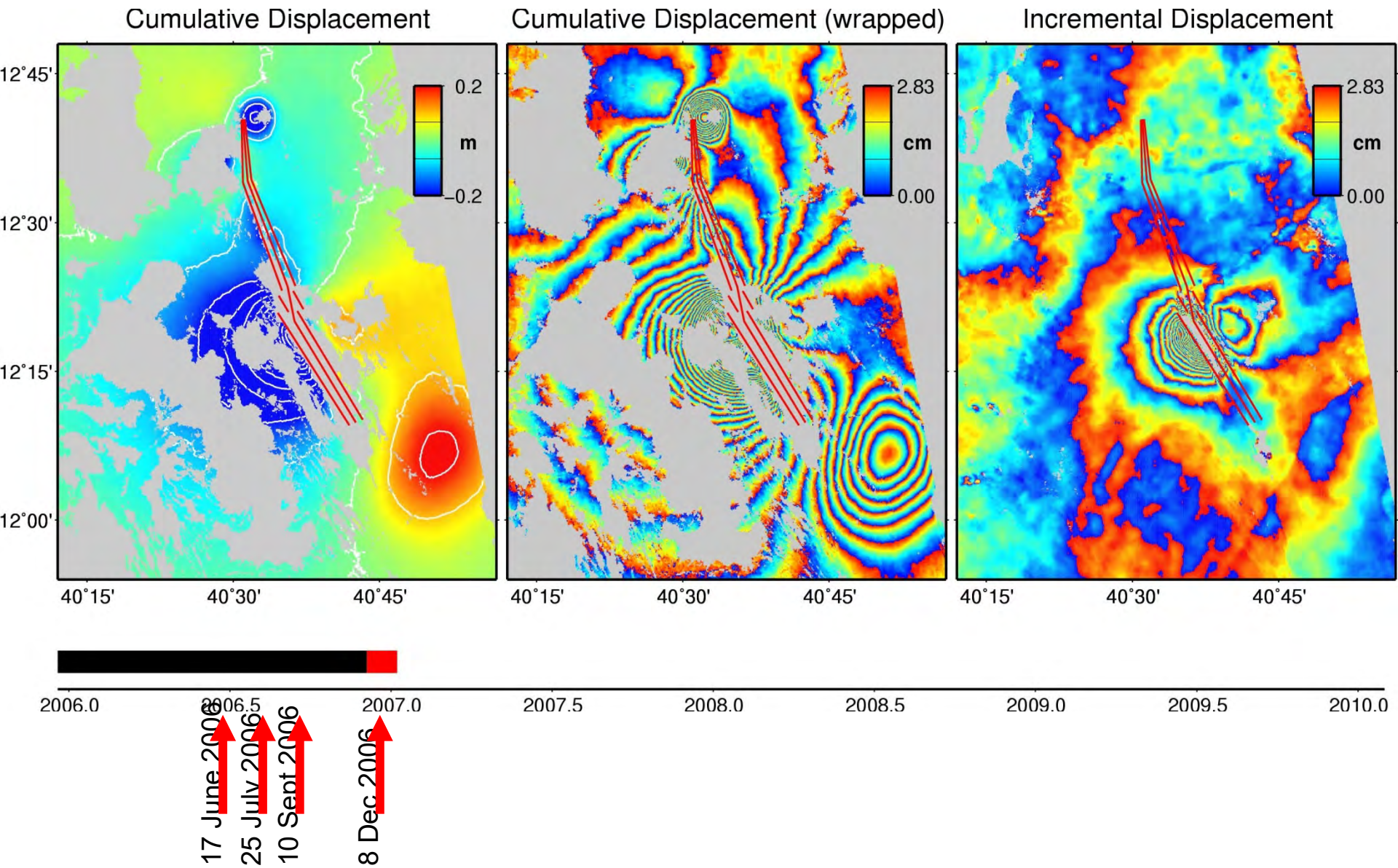
Post-intrusion deformation – Track 300



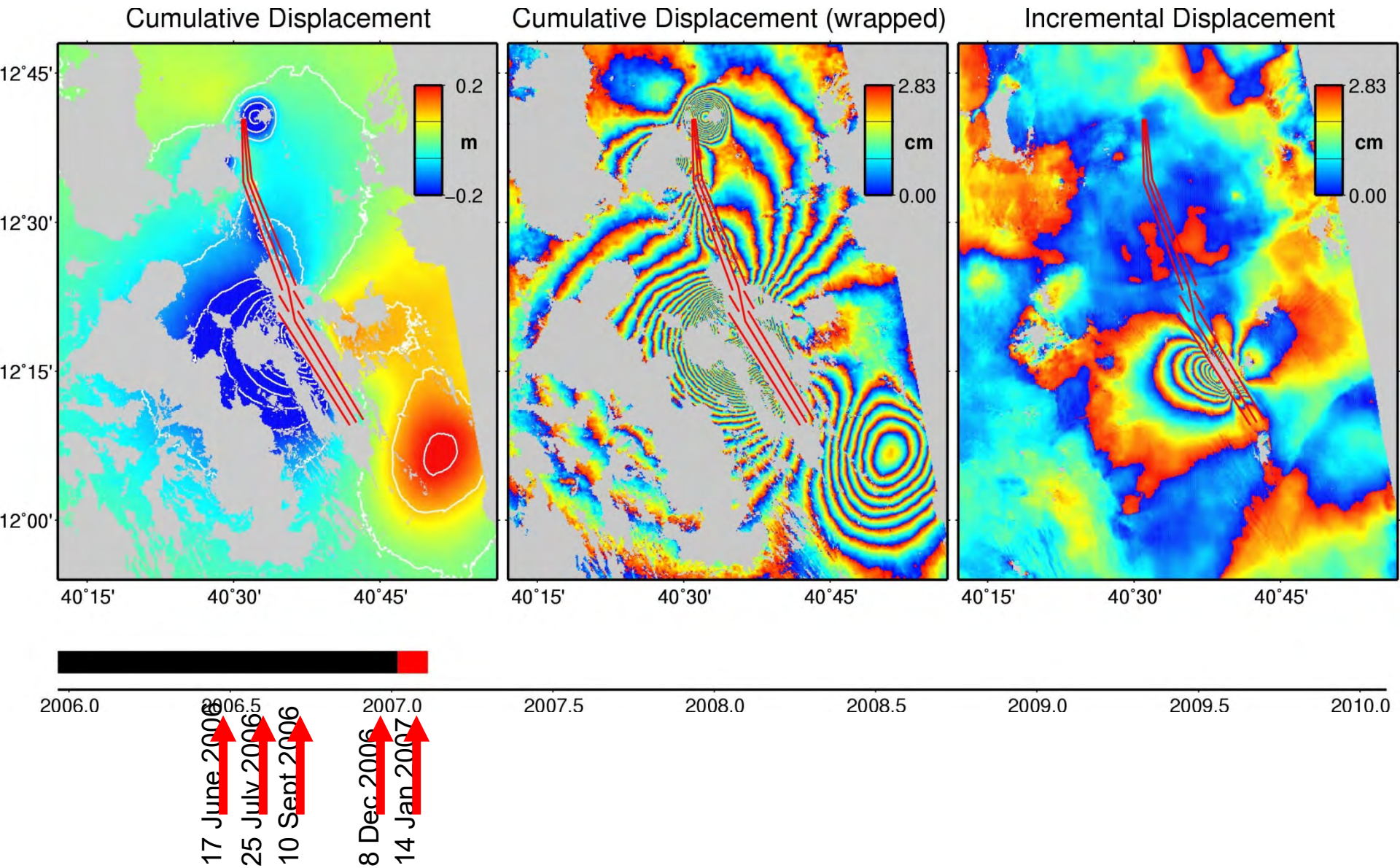
Post-intrusion deformation – Track 300



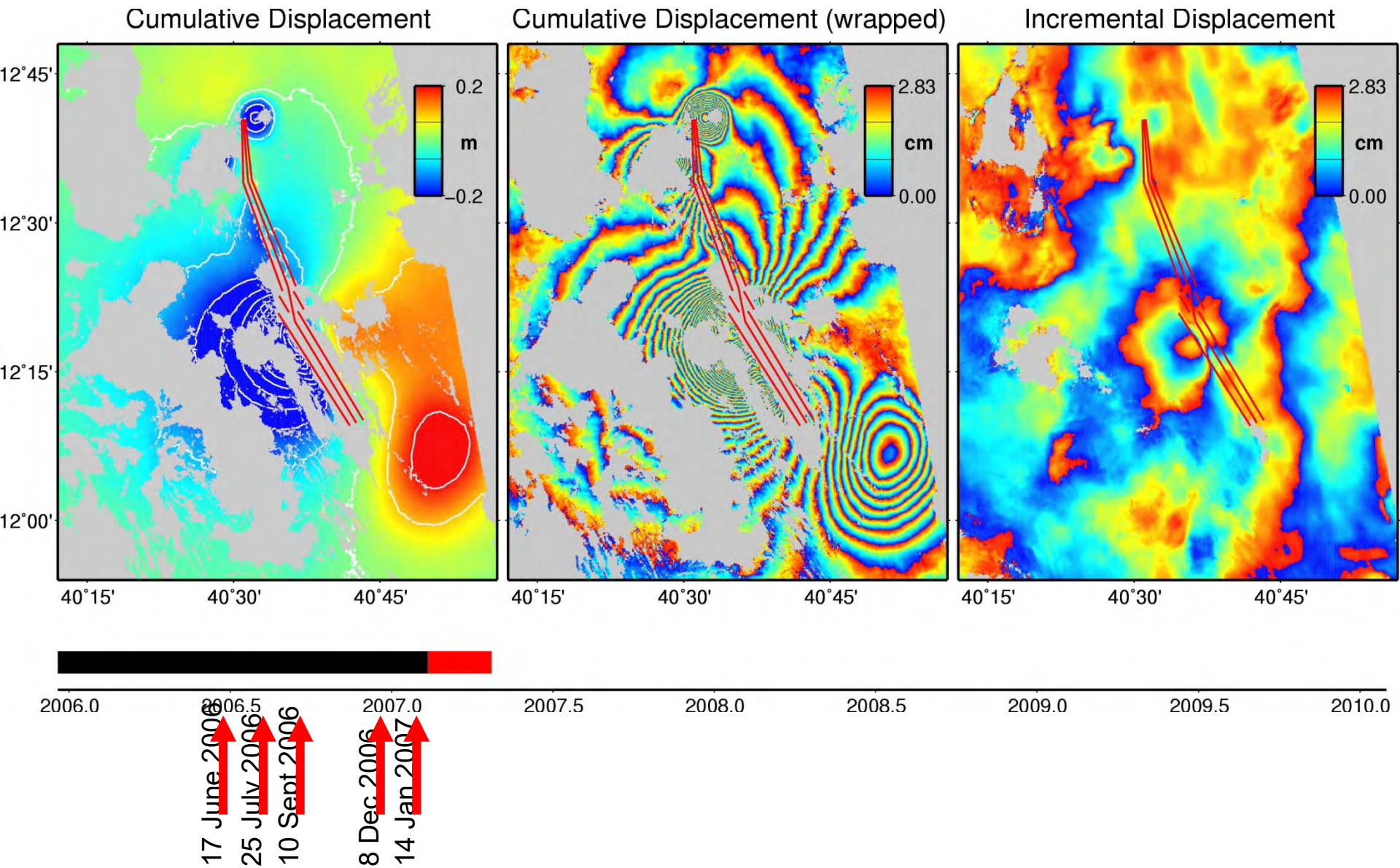
Post-intrusion deformation – Track 300



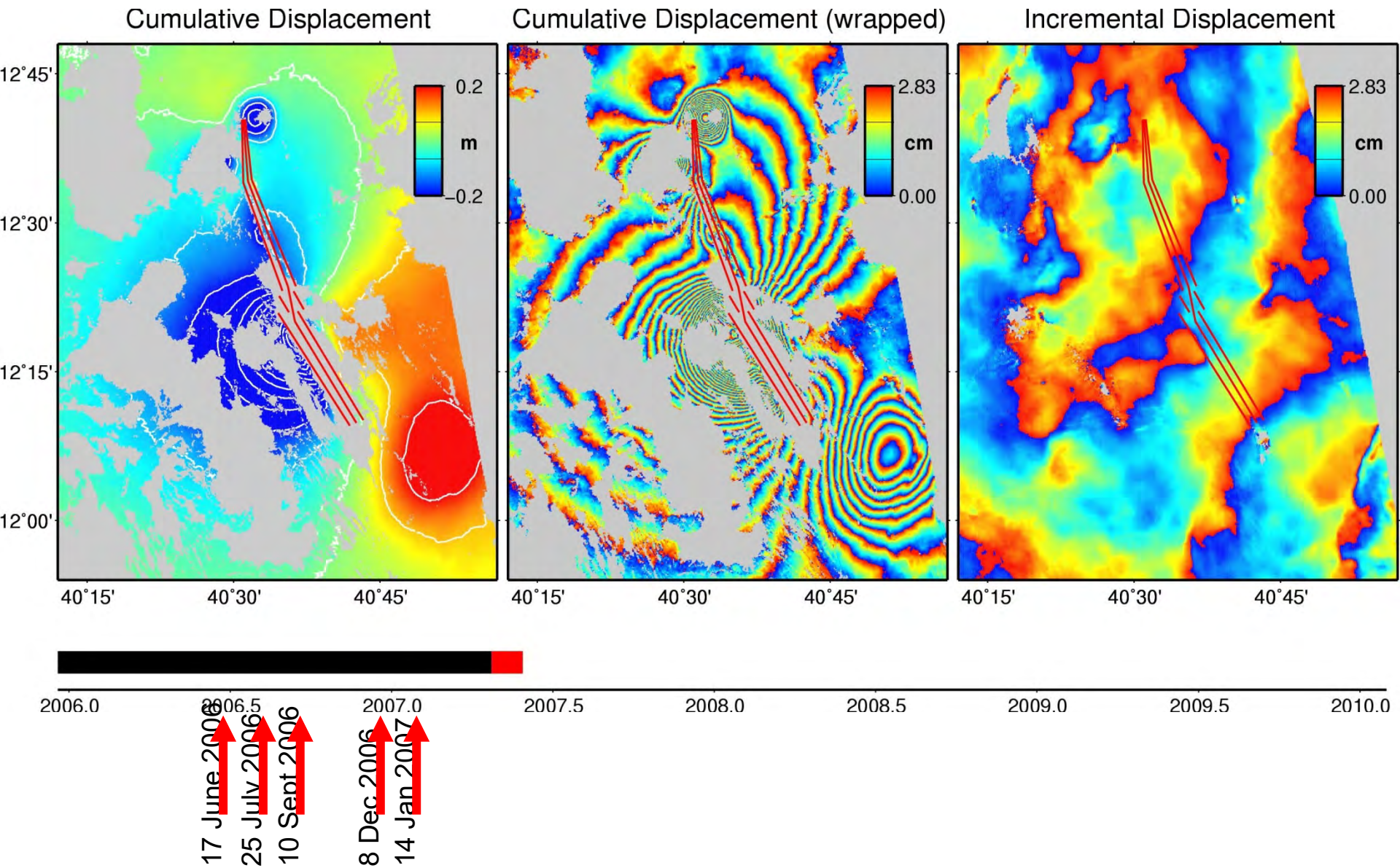
Post-intrusion deformation – Track 300



Post-intrusion deformation – Track 300



Post-intrusion deformation – Track 300



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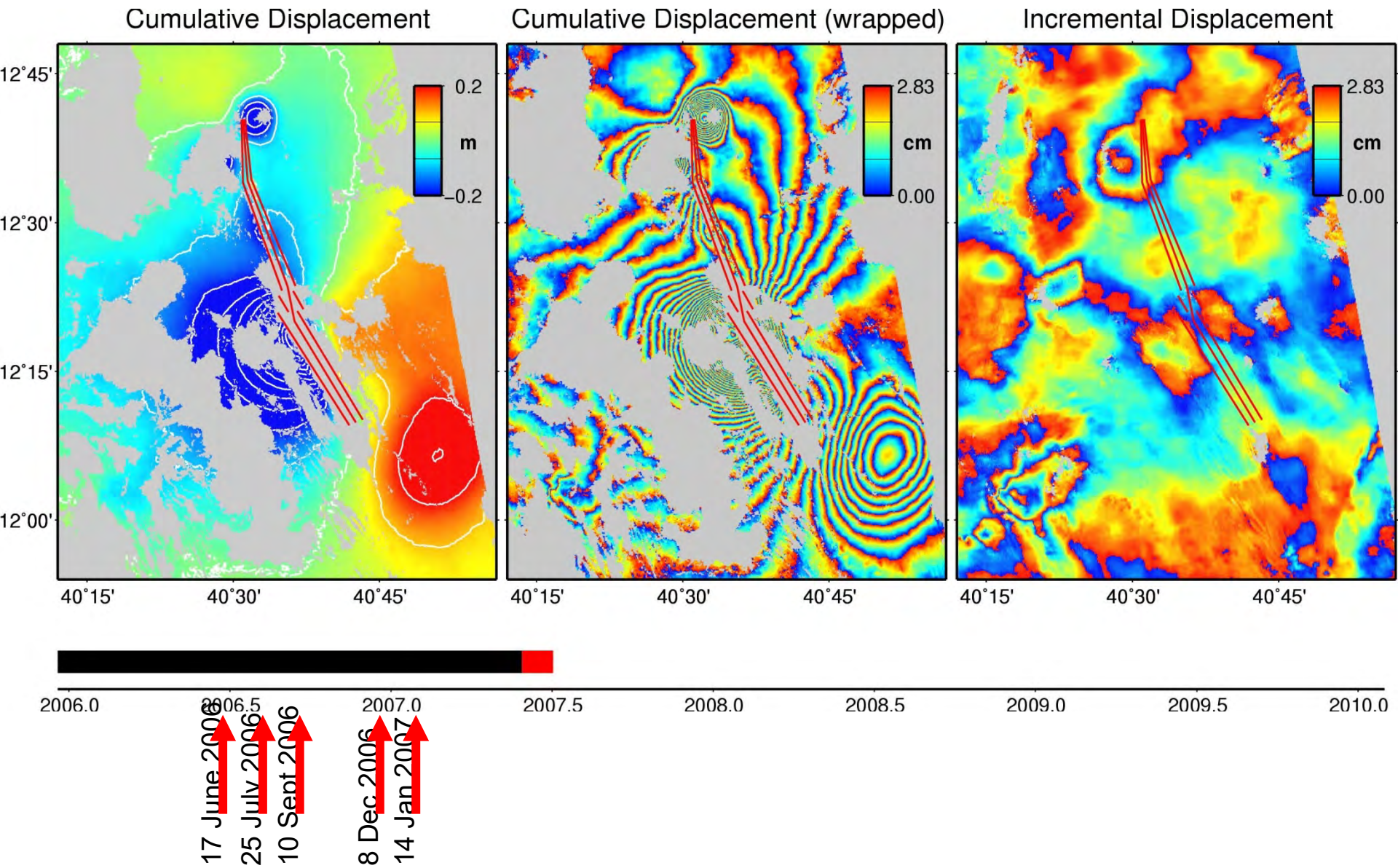
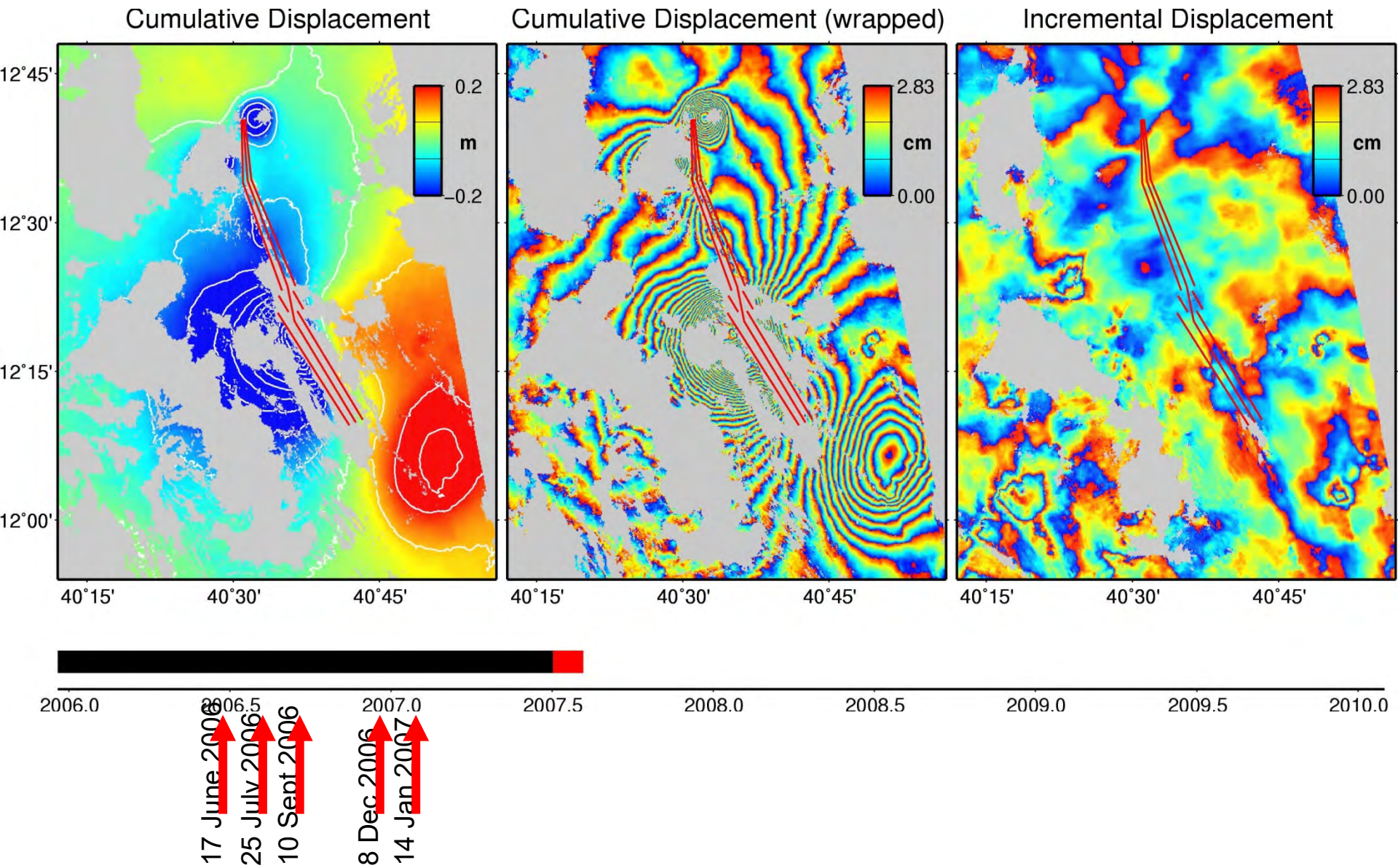
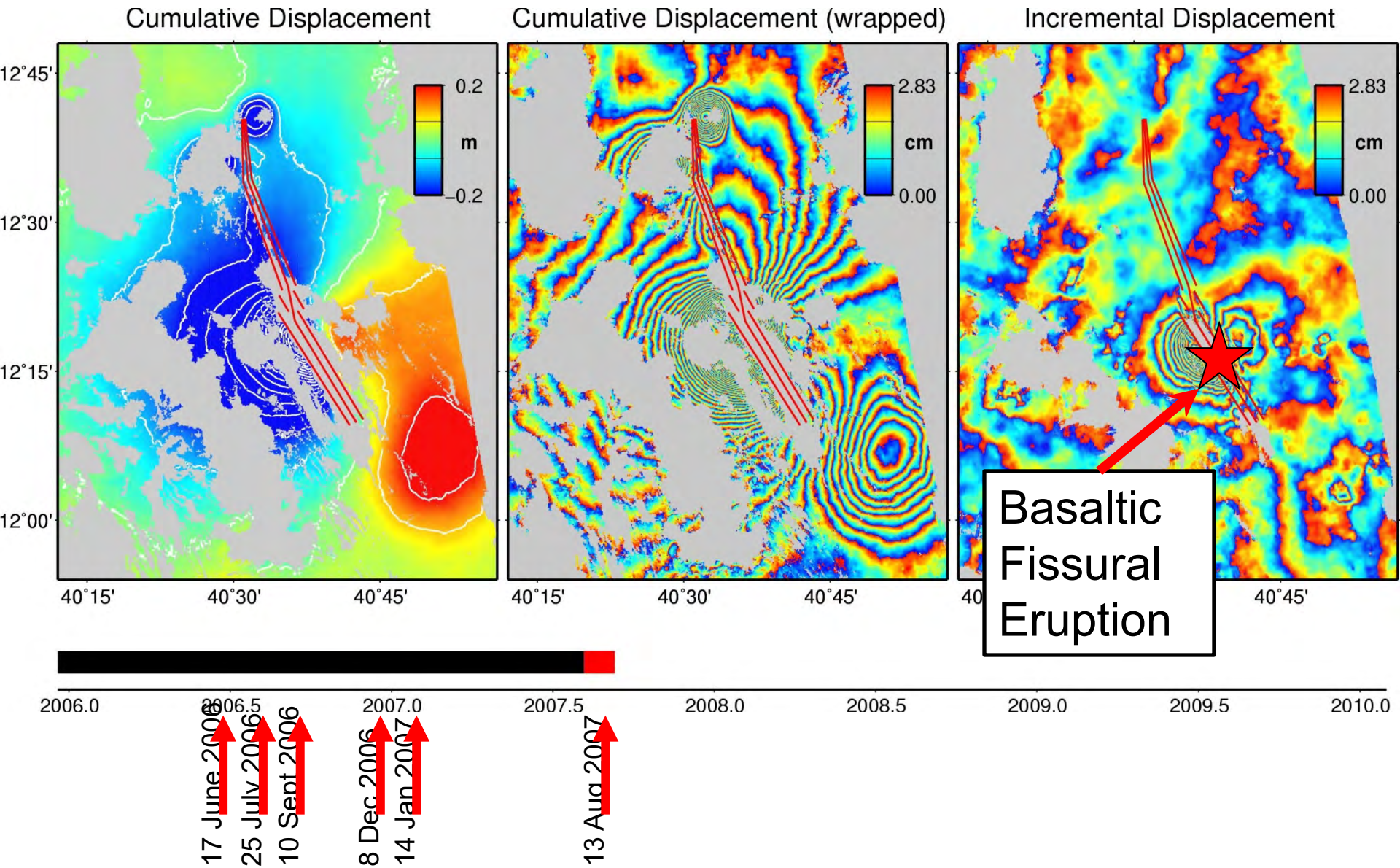


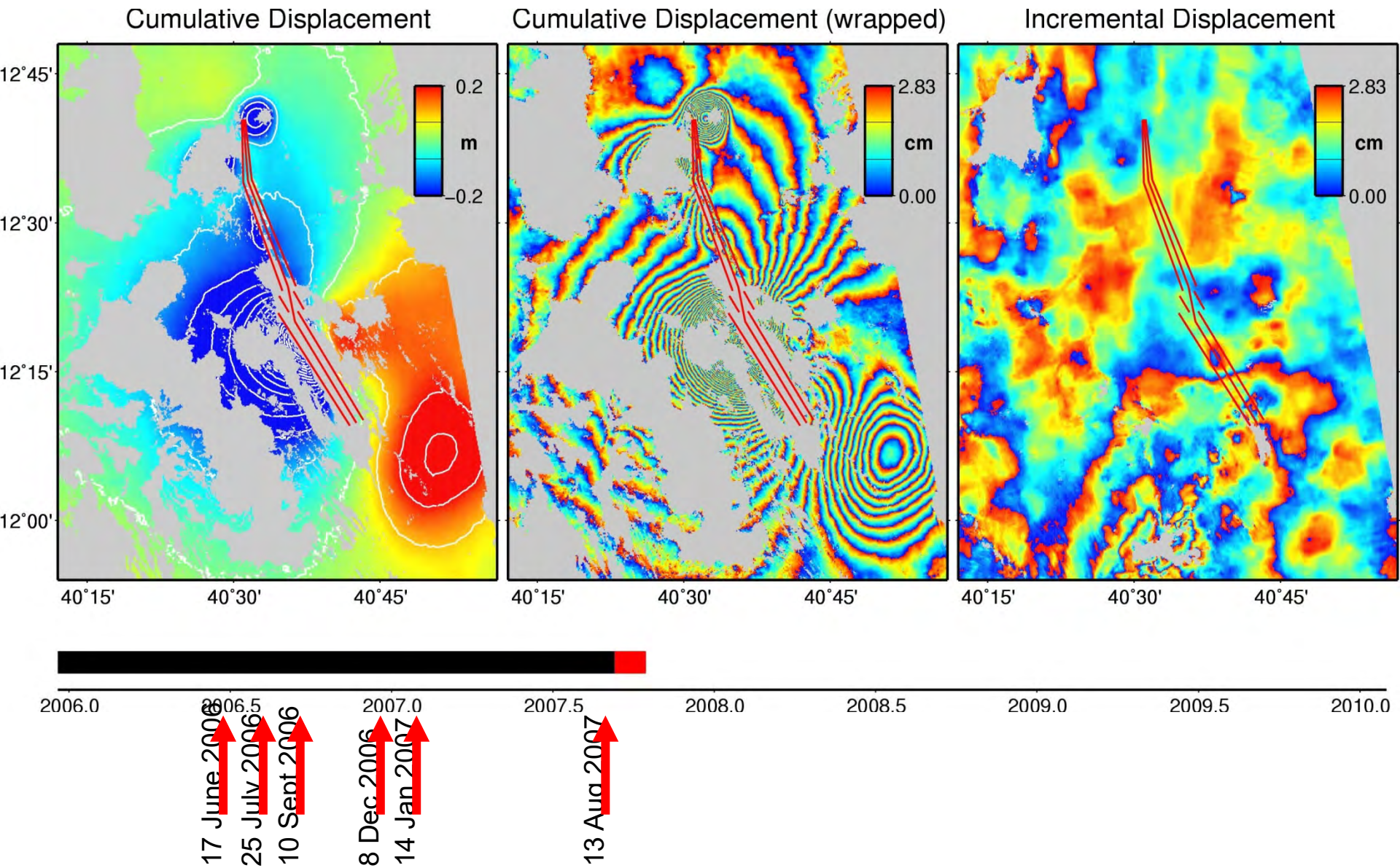
Post-intrusion deformation – Track 300



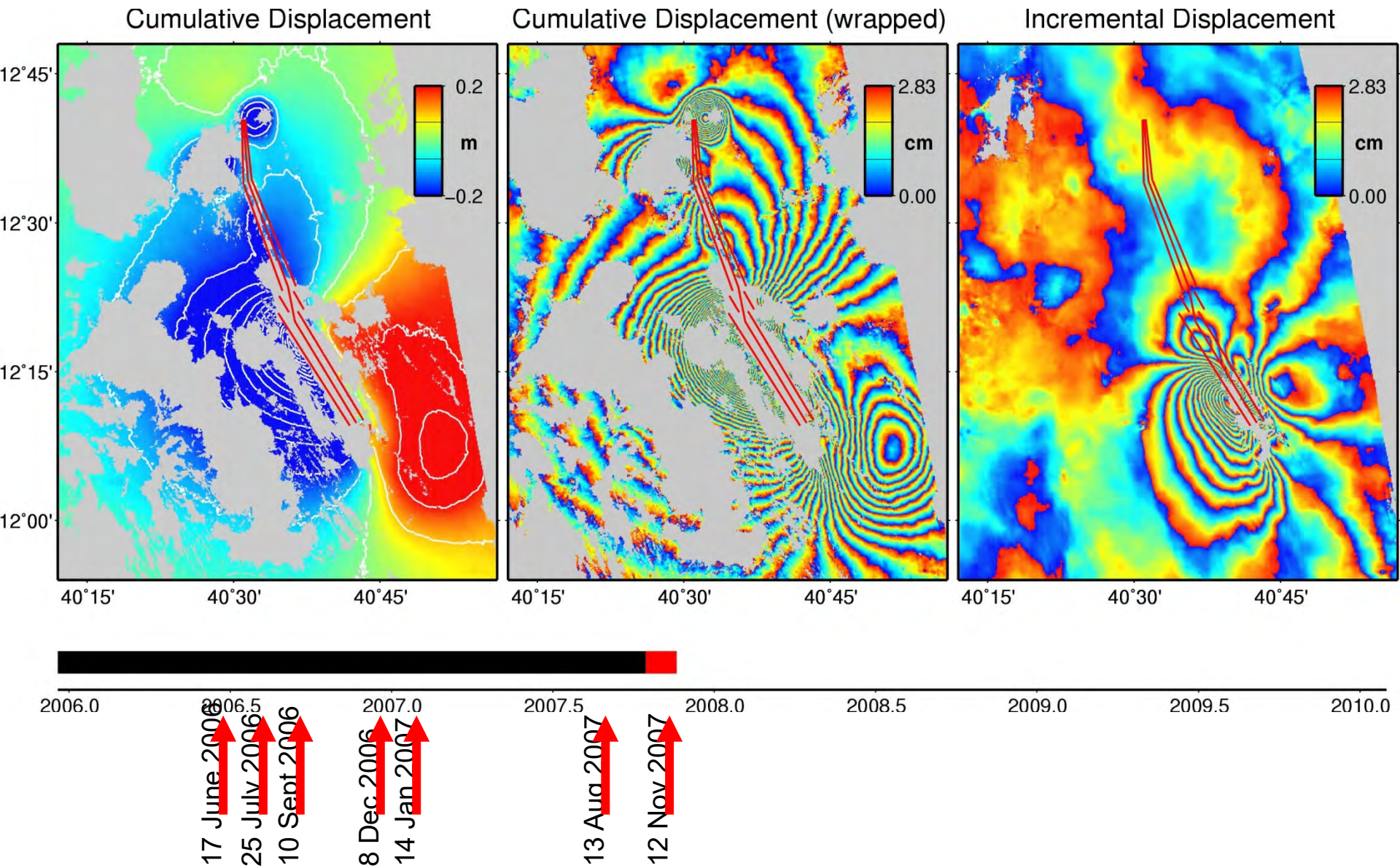
Post-intrusion deformation – Track 300



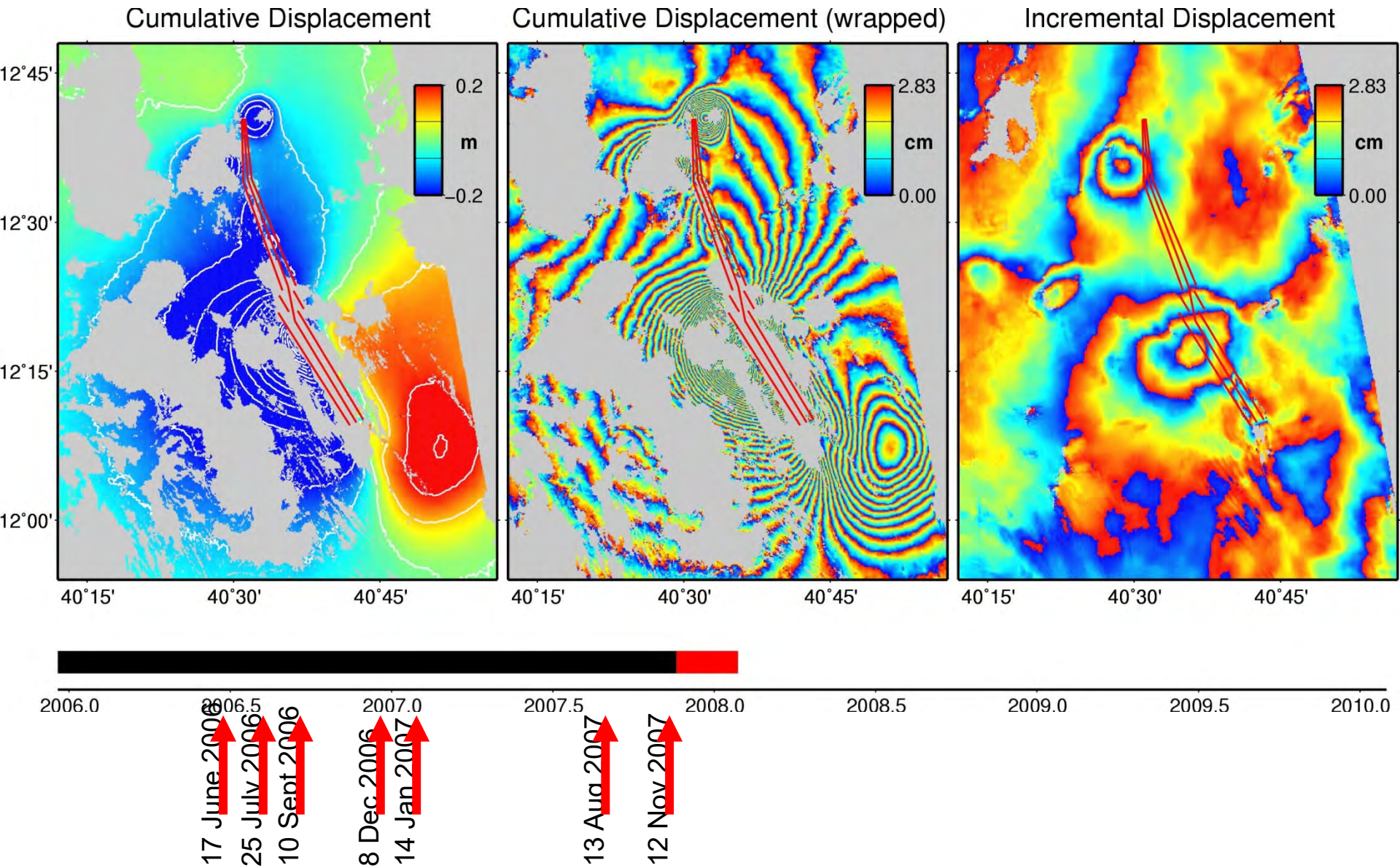
Post-intrusion deformation – Track 300



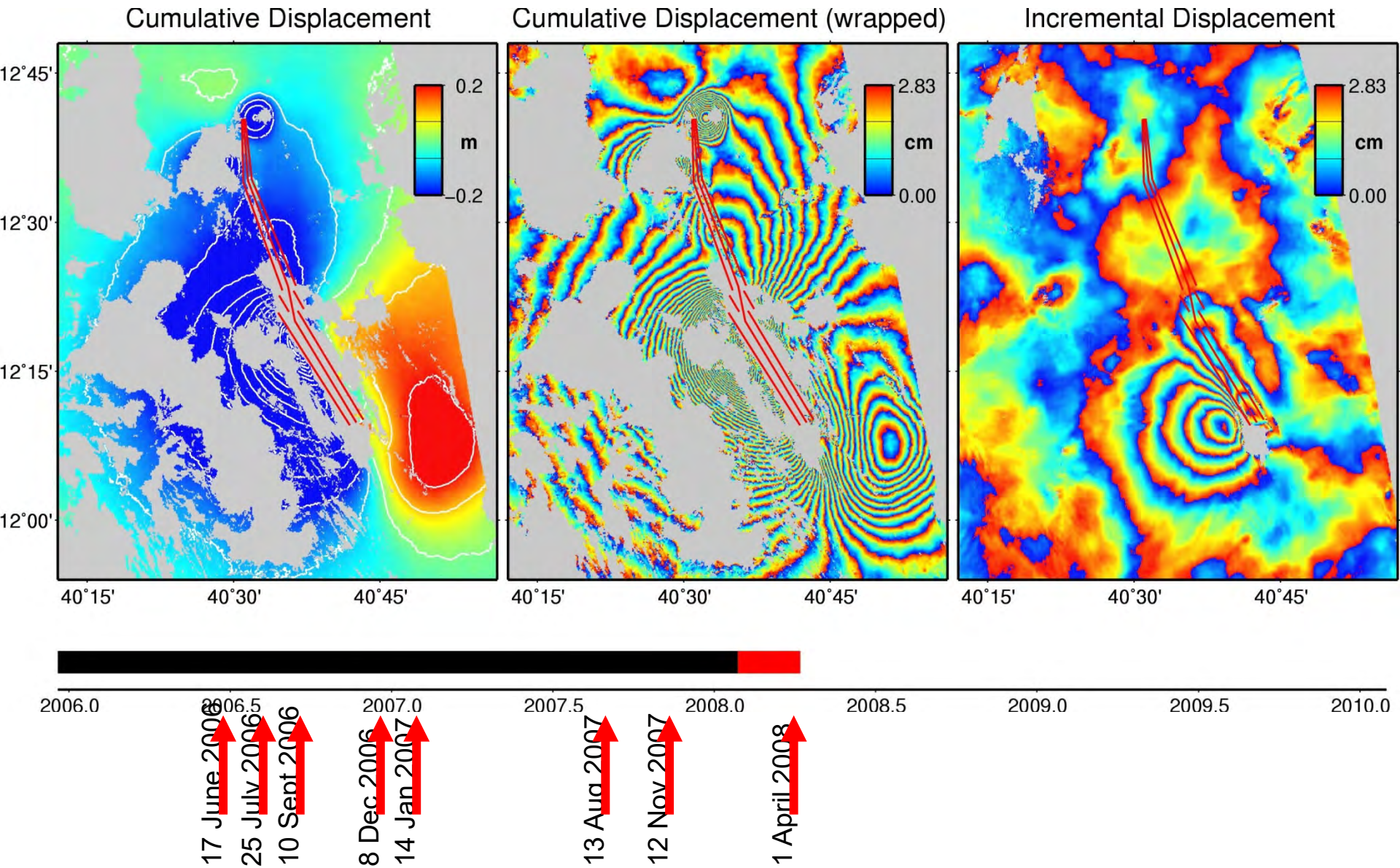
Post-intrusion deformation – Track 300



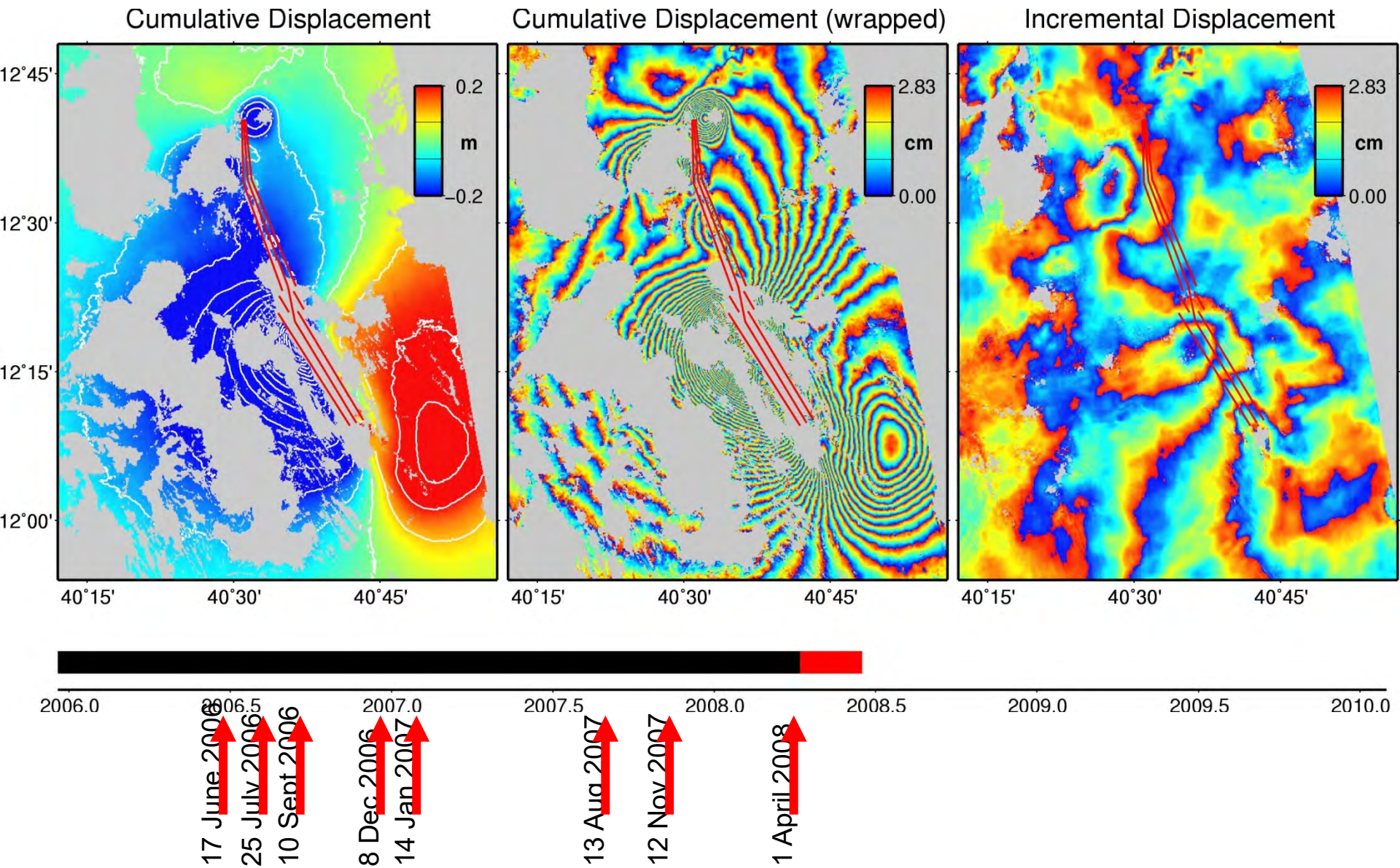
Post-intrusion deformation – Track 300



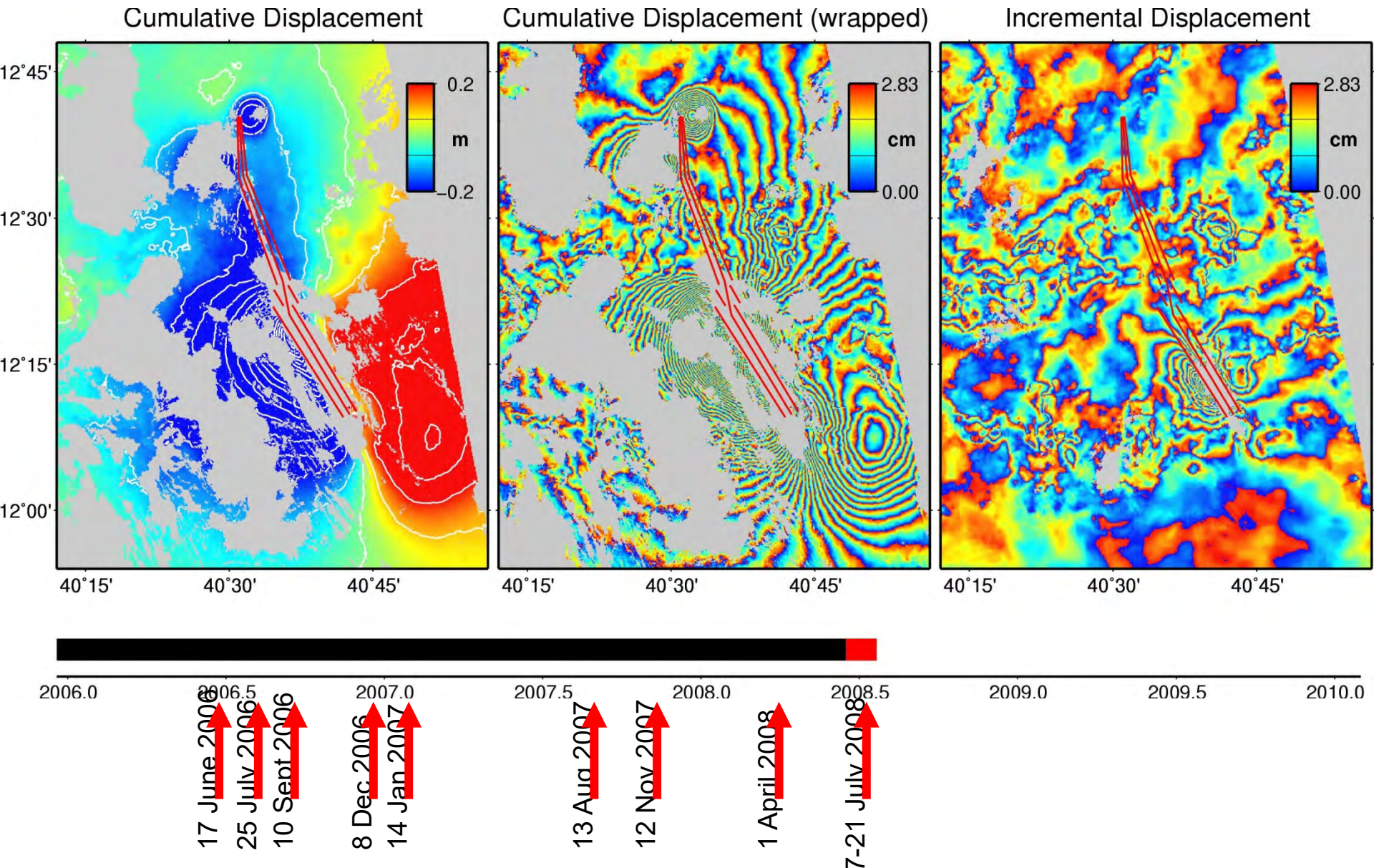
Post-intrusion deformation – Track 300



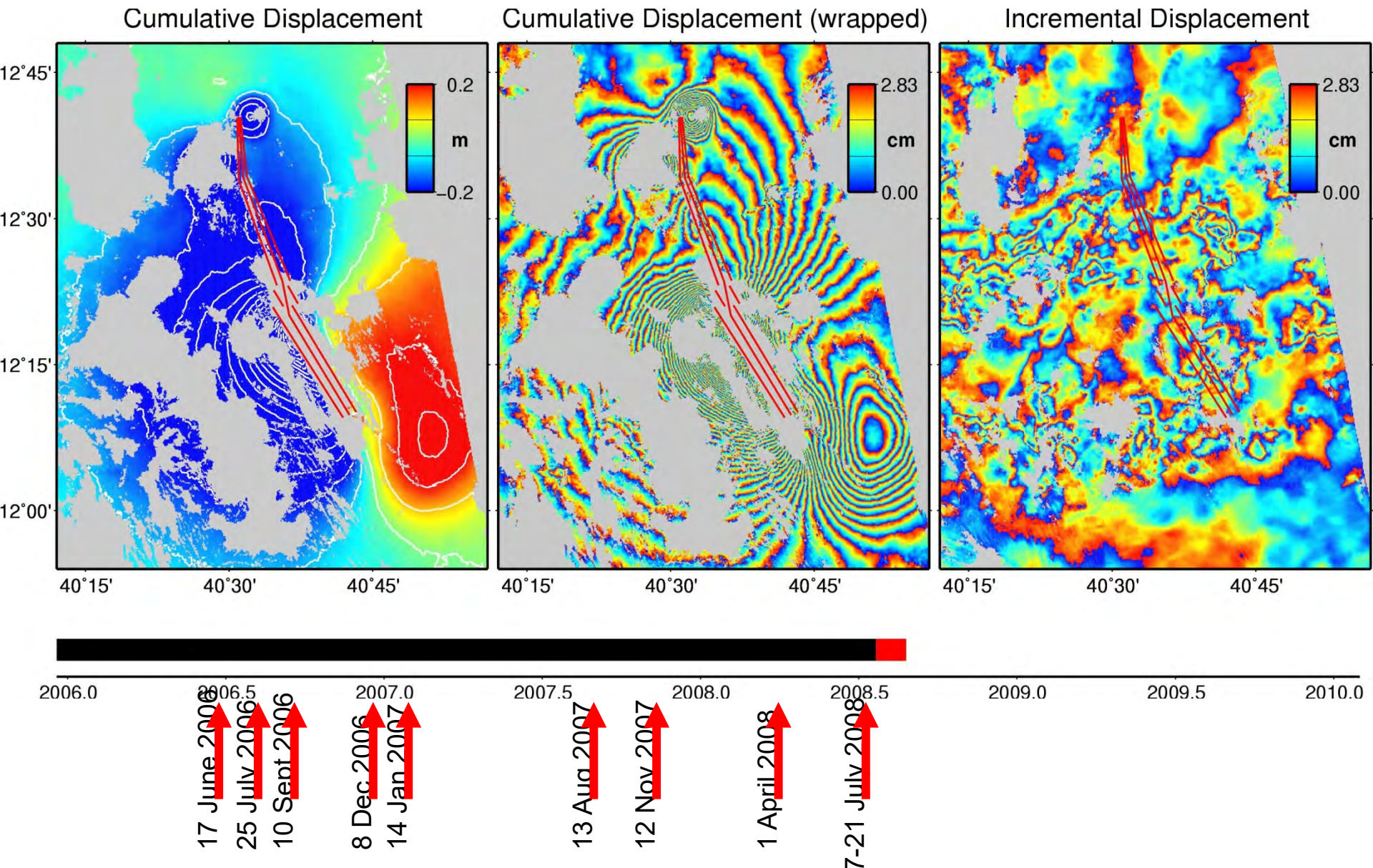
Post-intrusion deformation – Track 300



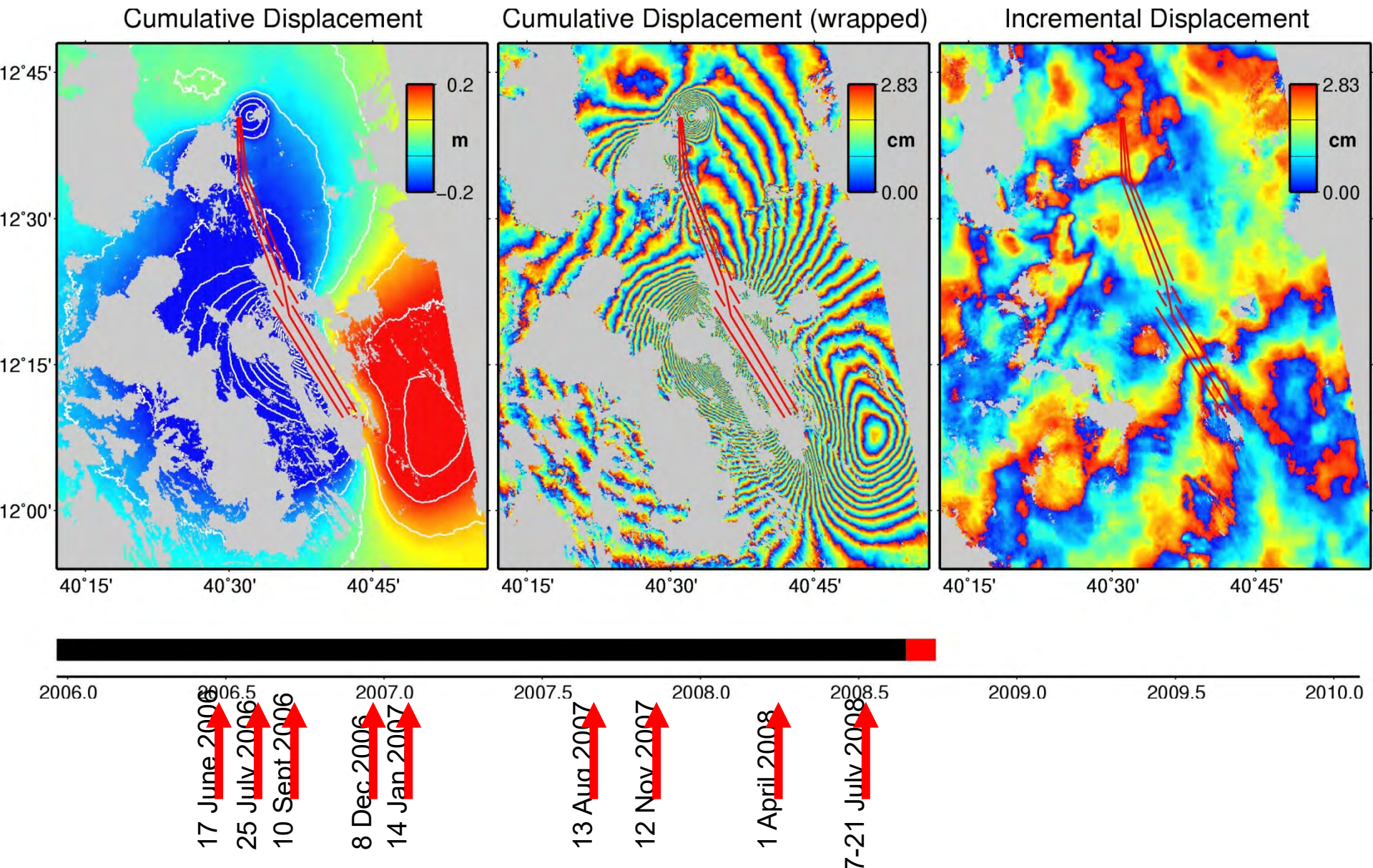
Post-intrusion deformation – Track 300



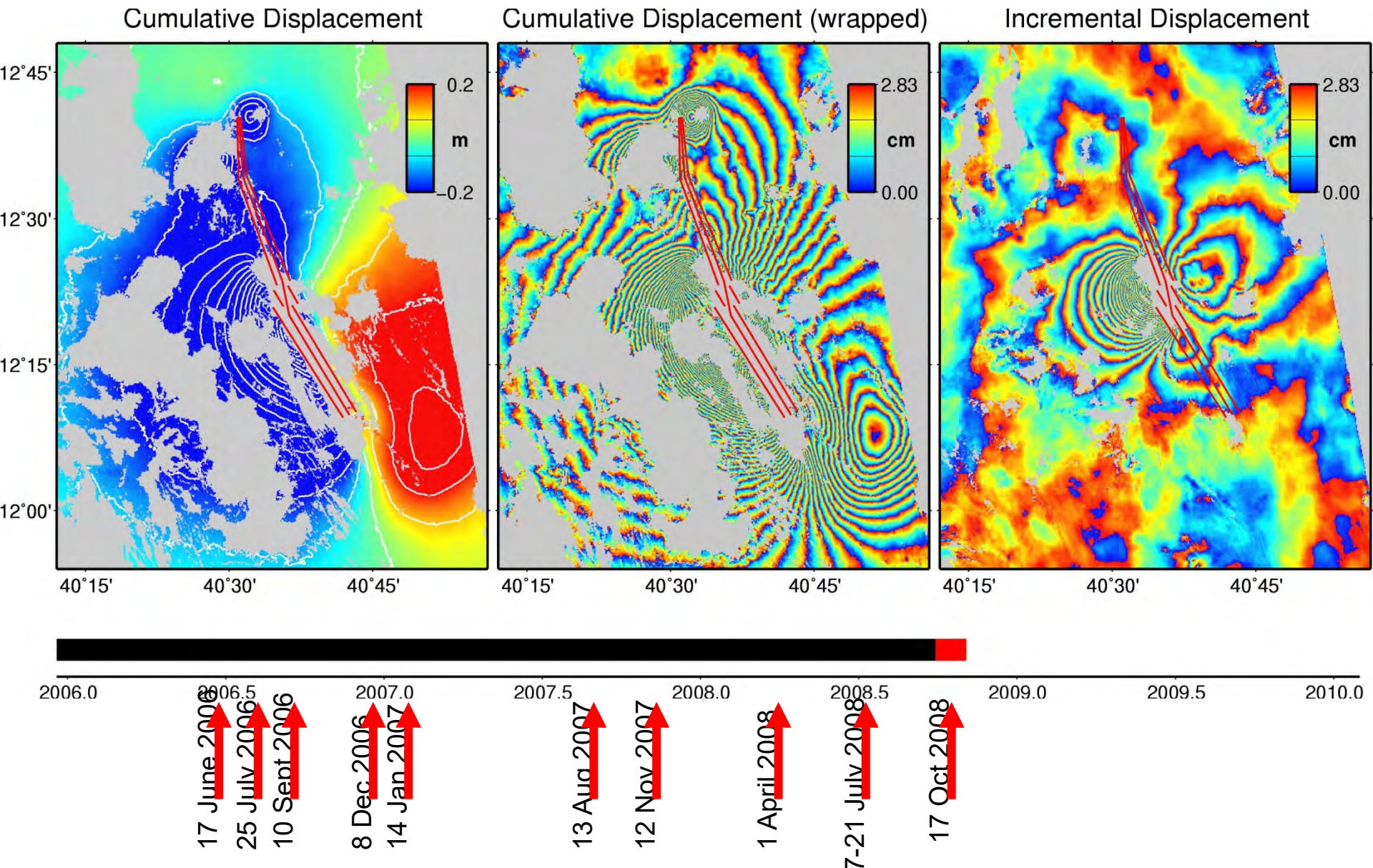
Post-intrusion deformation – Track 300



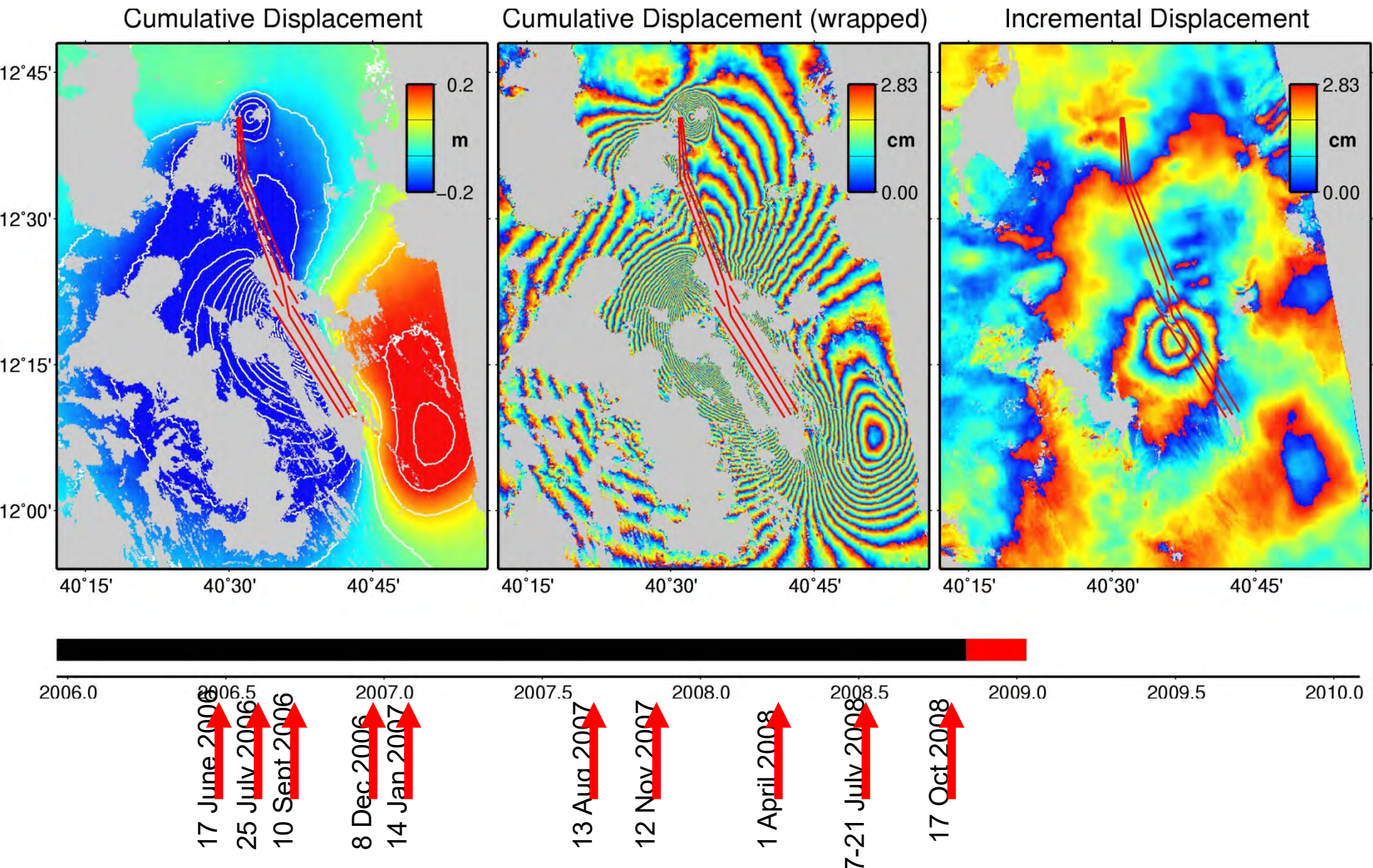
Post-intrusion deformation – Track 300



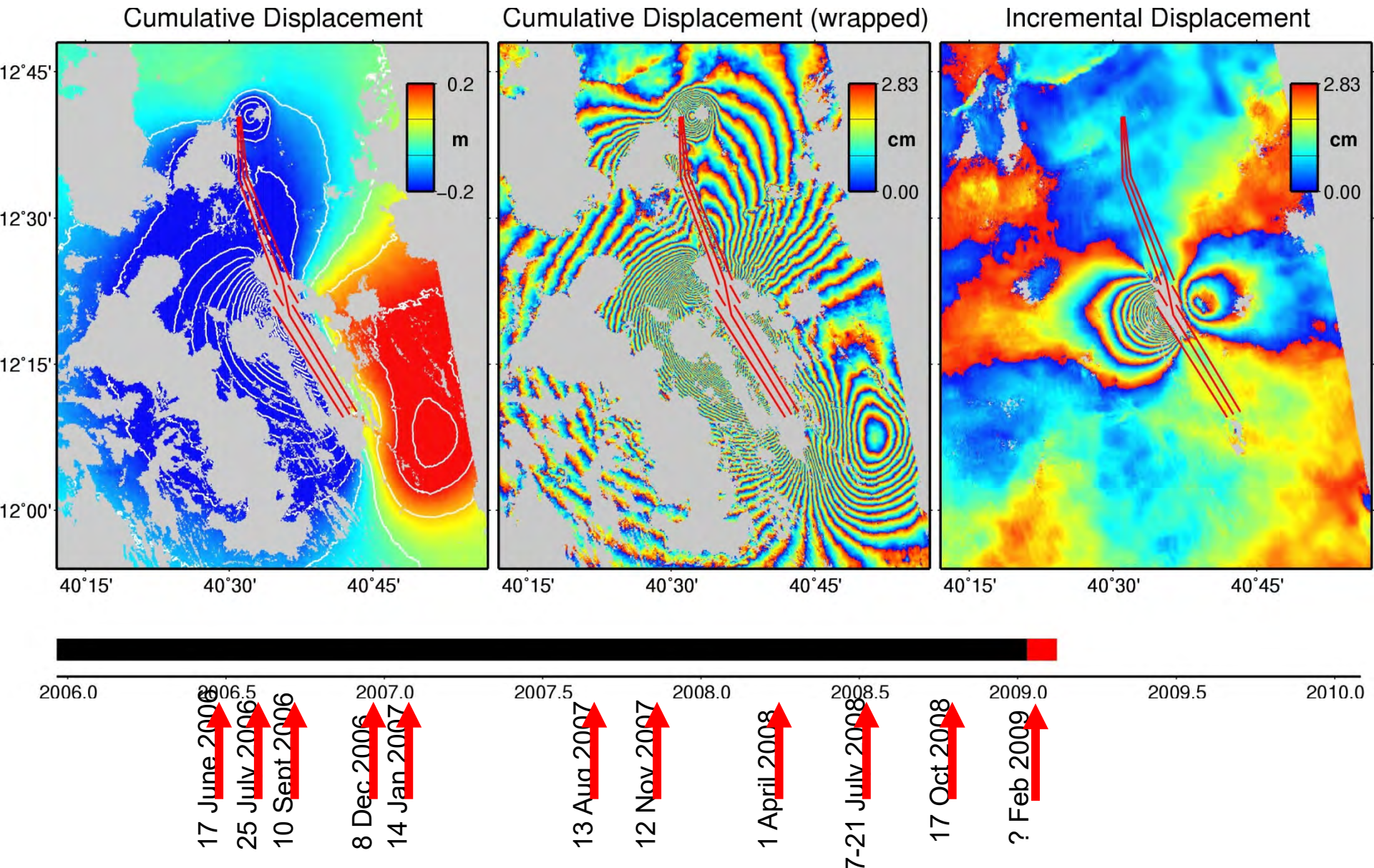
Post-intrusion deformation – Track 300



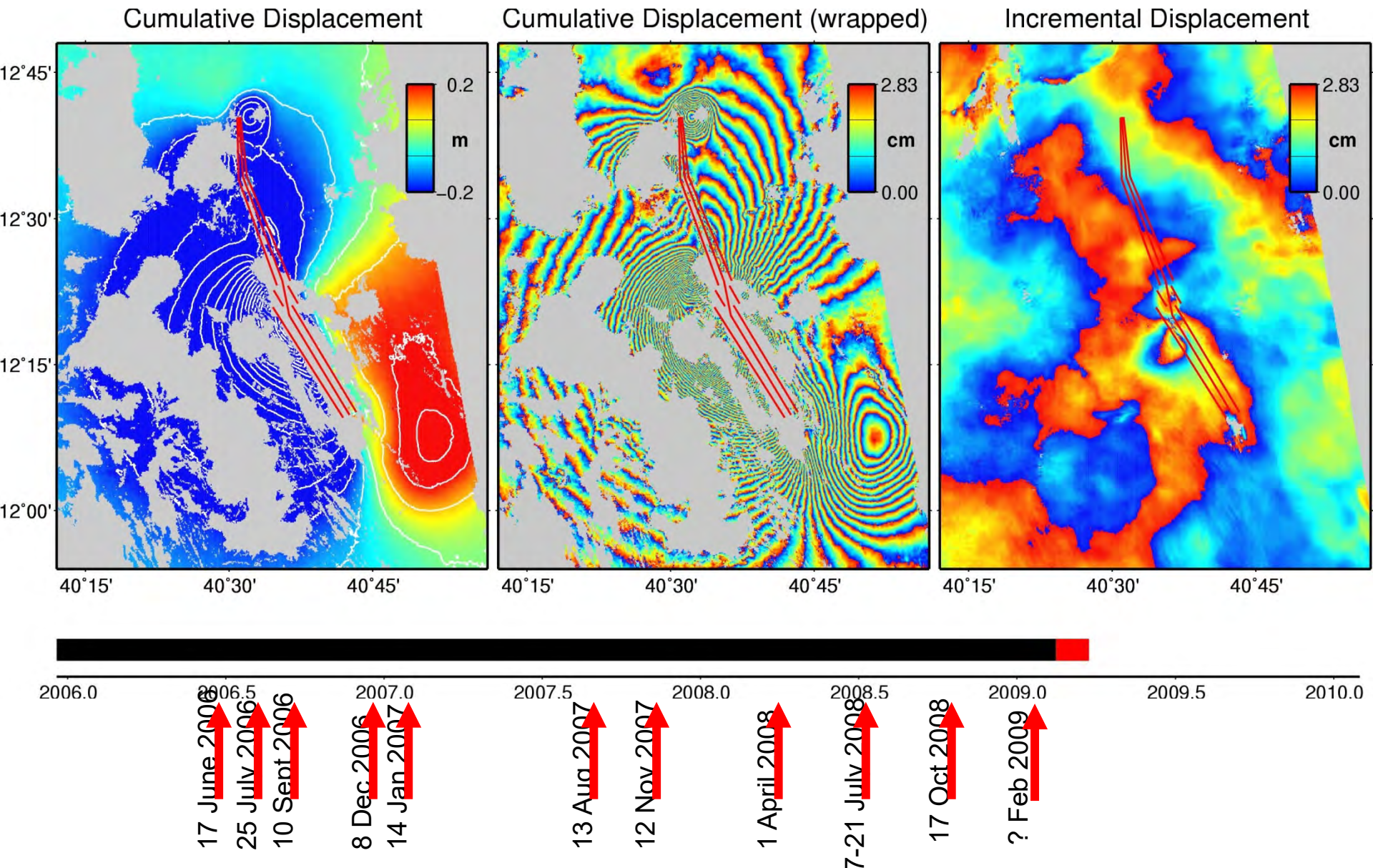
Post-intrusion deformation – Track 300



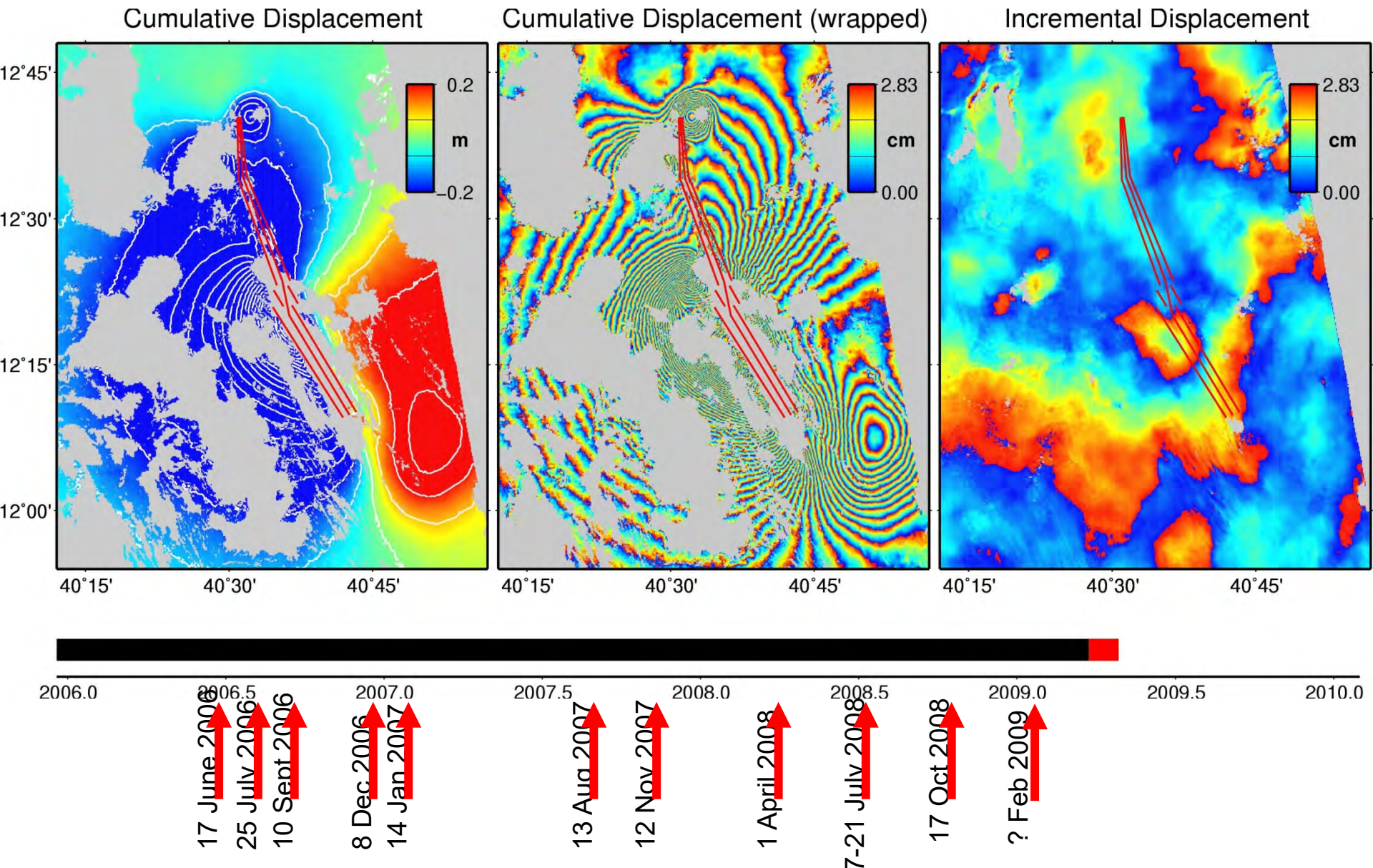
Post-intrusion deformation – Track 300



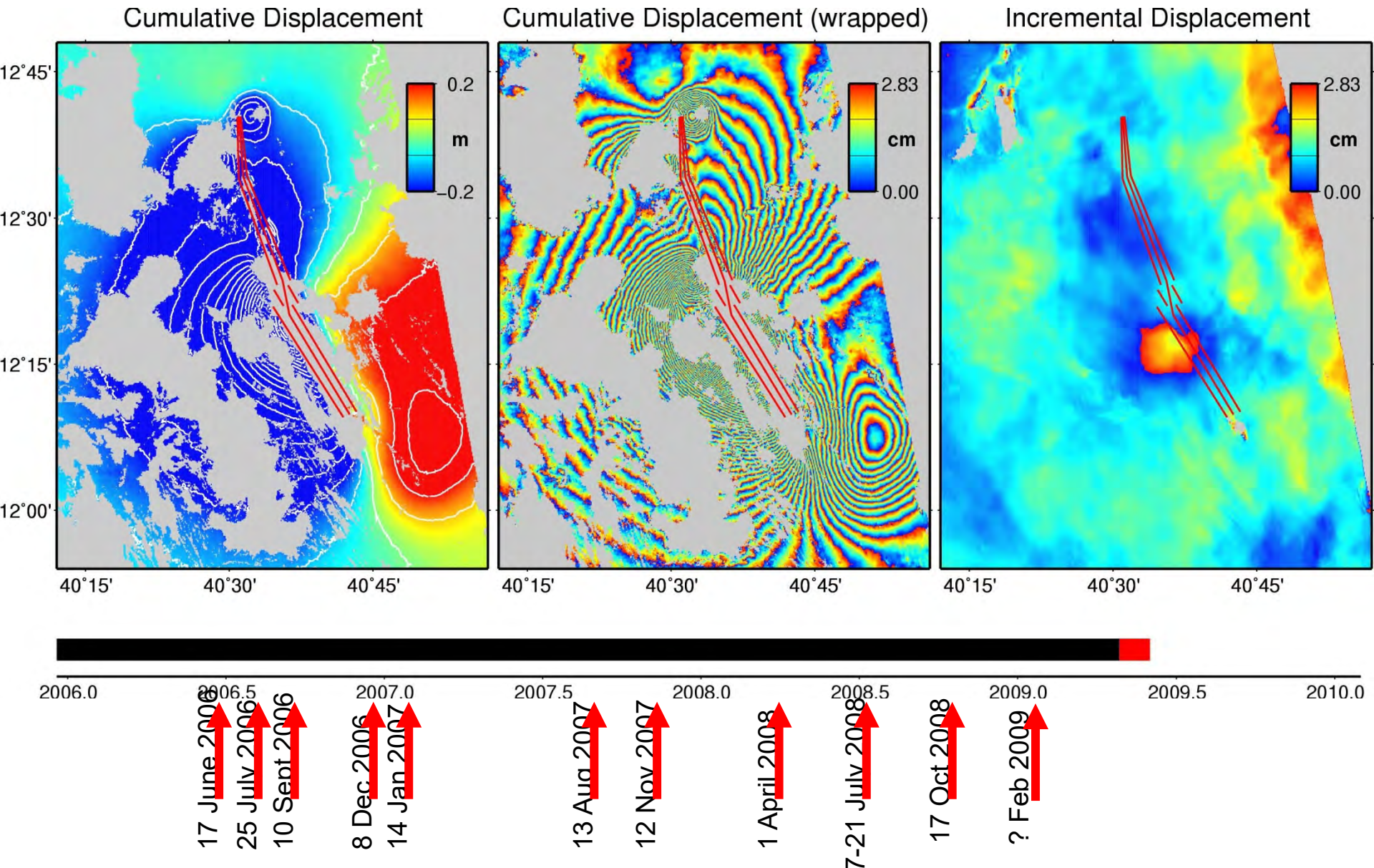
Post-intrusion deformation – Track 300



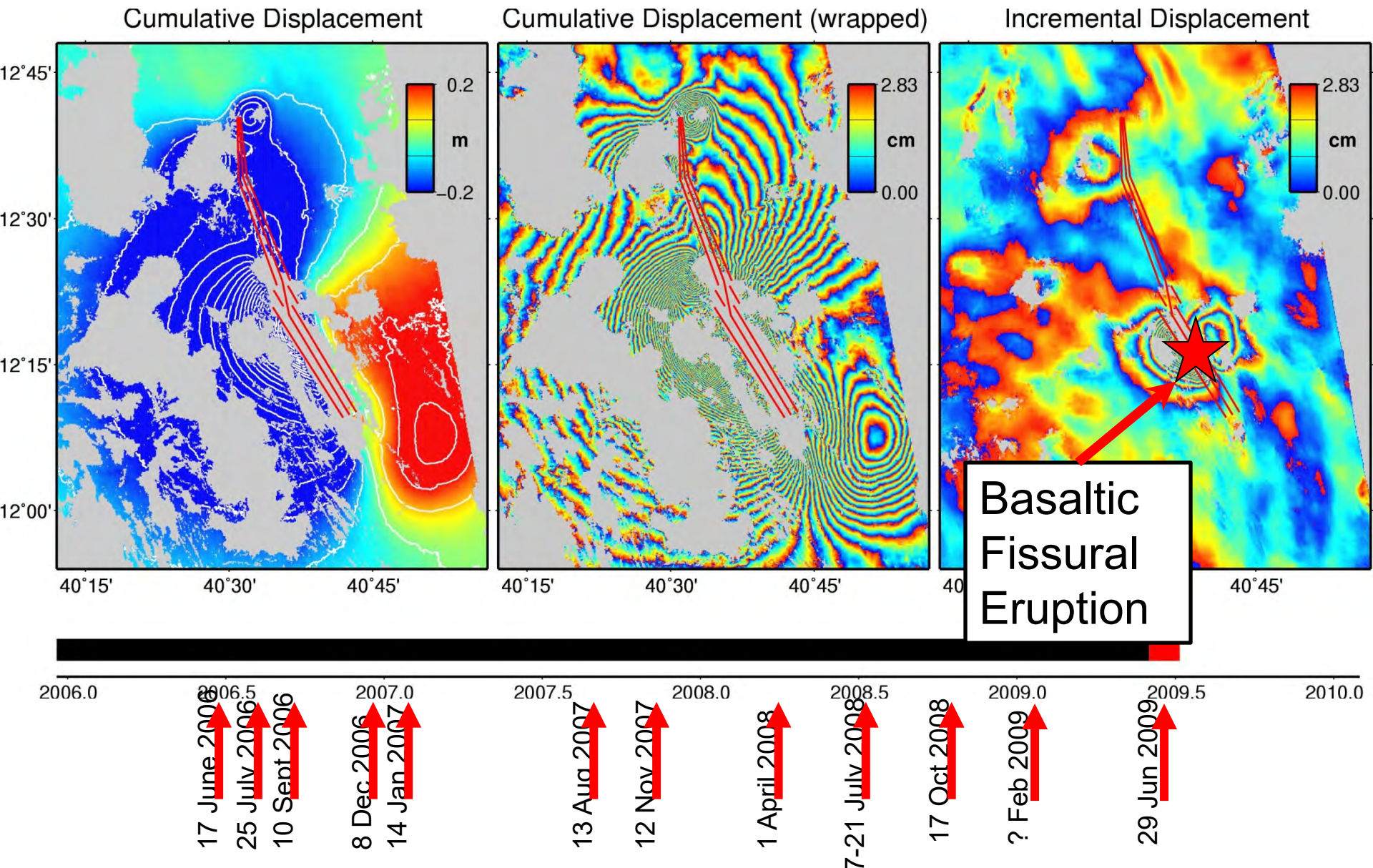
Post-intrusion deformation – Track 300



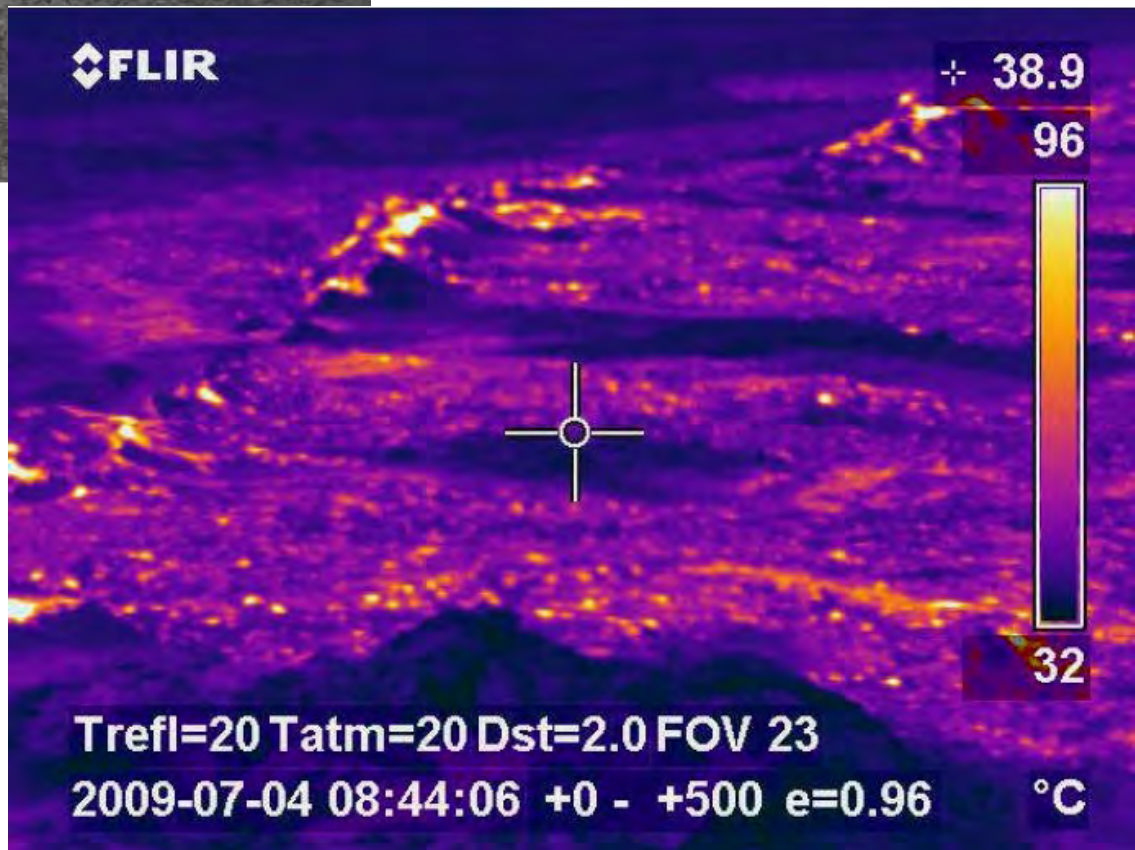
Post-intrusion deformation – Track 300



Post-intrusion deformation – Track 300

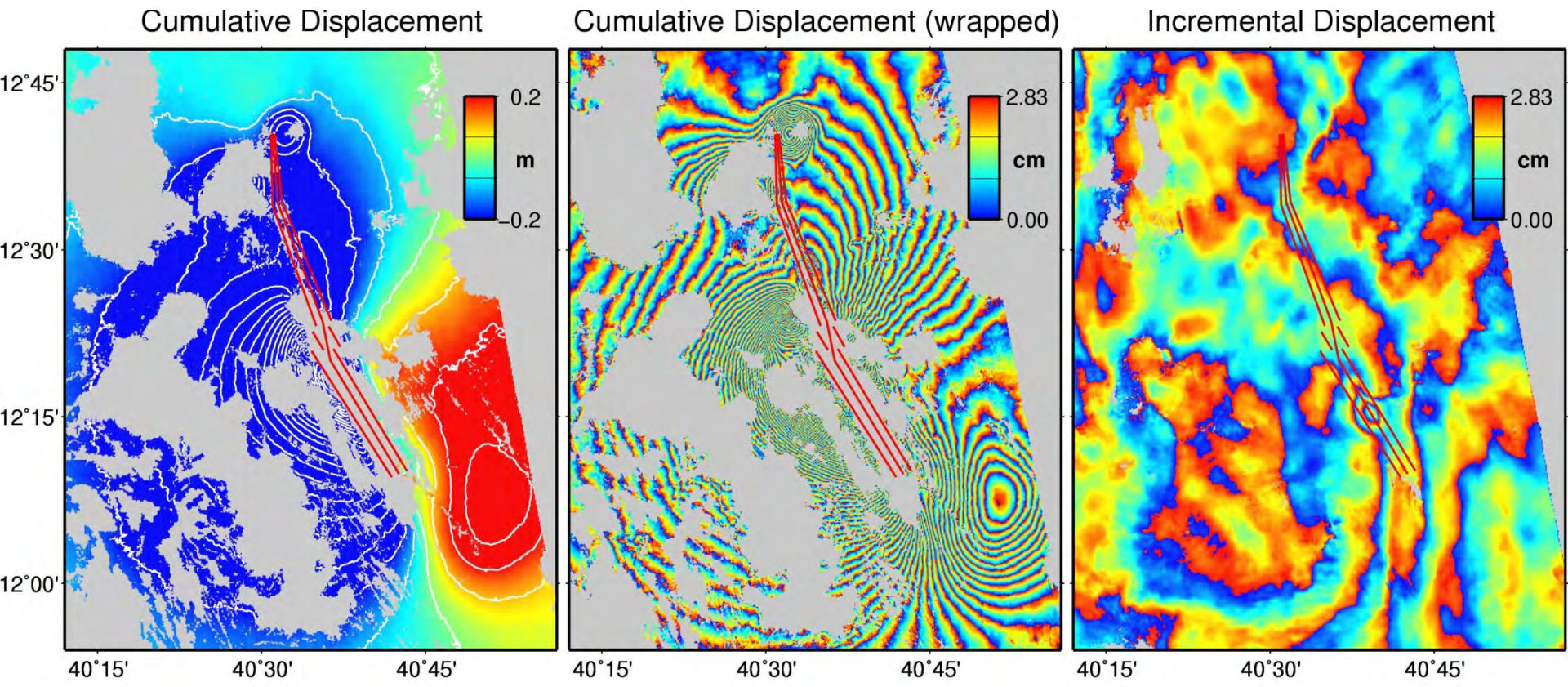


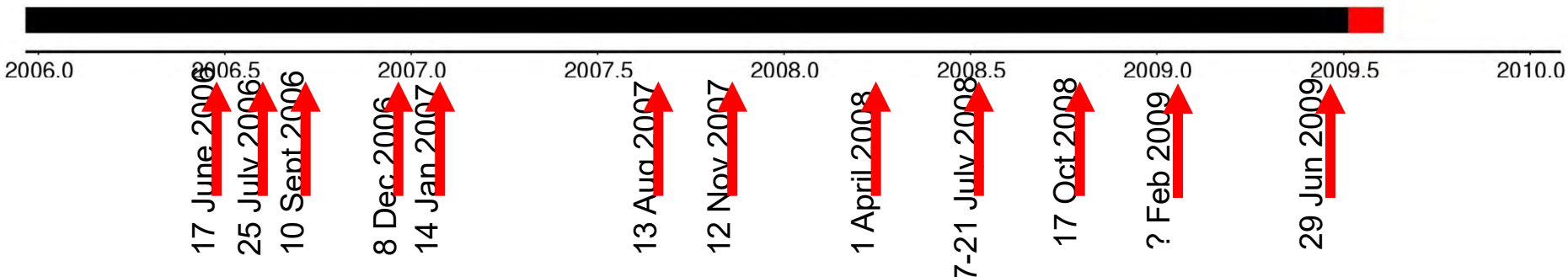
June 2009 dyke and eruption



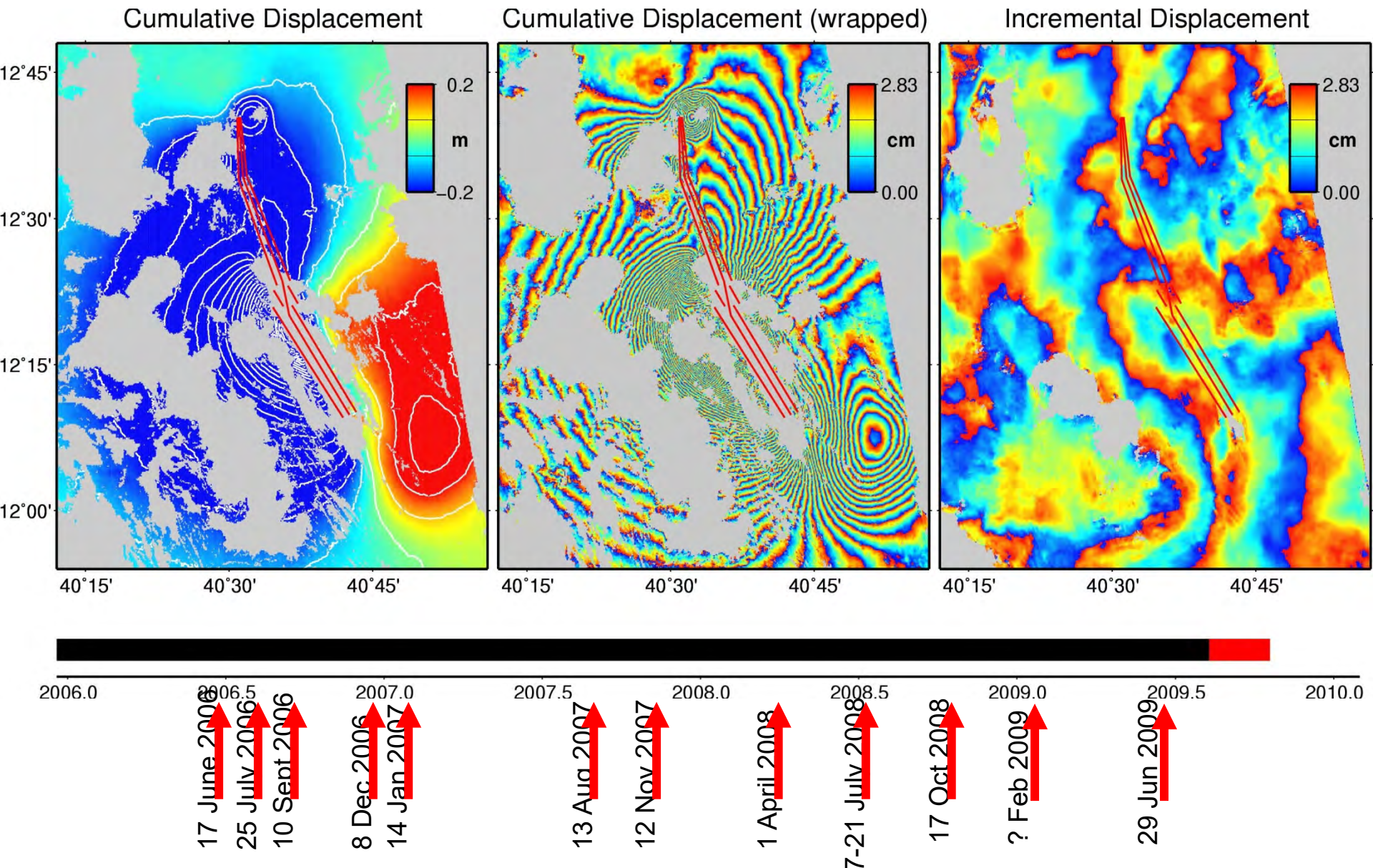
From Field Report, Yirgu et al, 2009

Post-intrusion deformation – Track 300

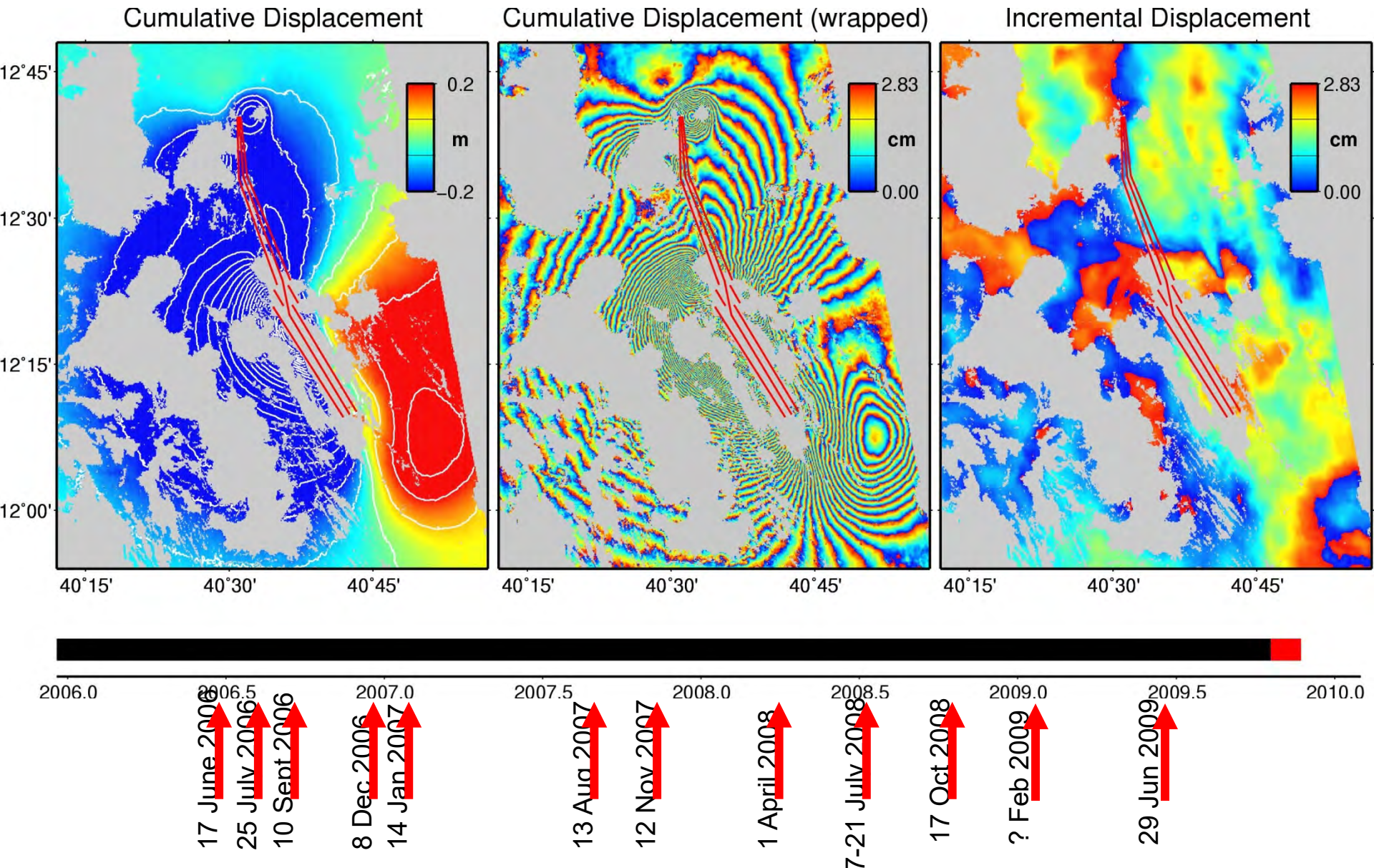




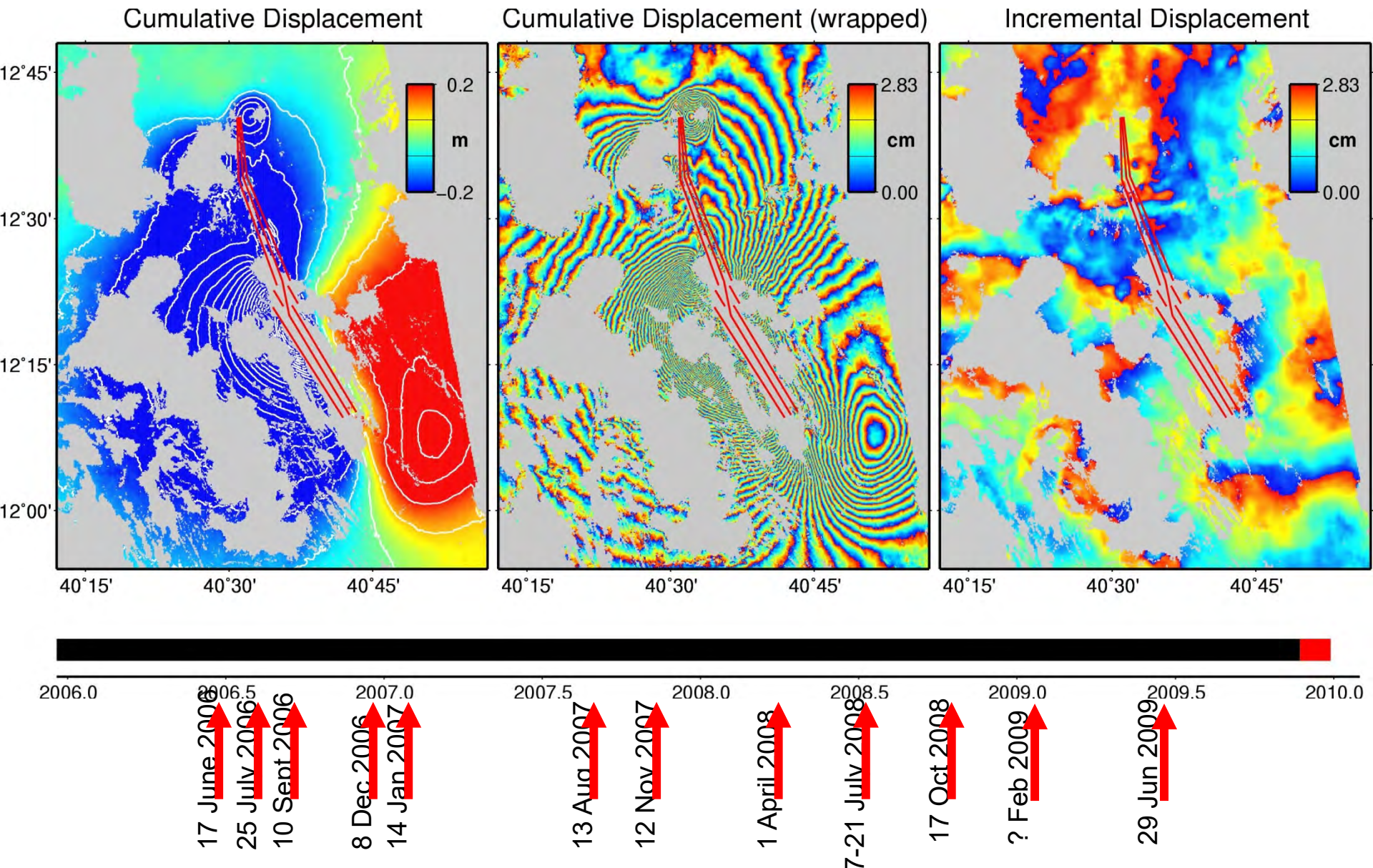
Post-intrusion deformation – Track 300



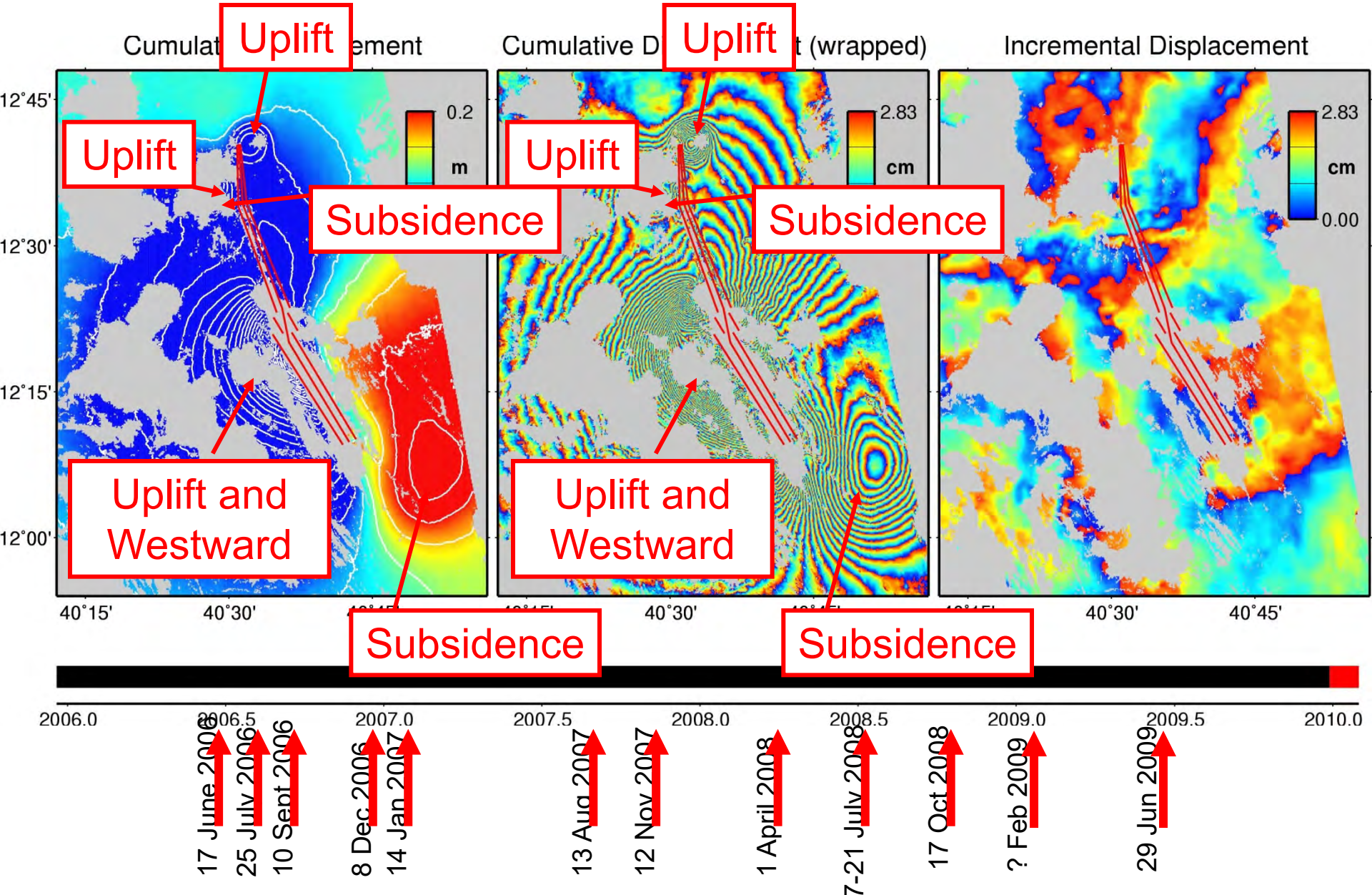
Post-intrusion deformation – Track 300

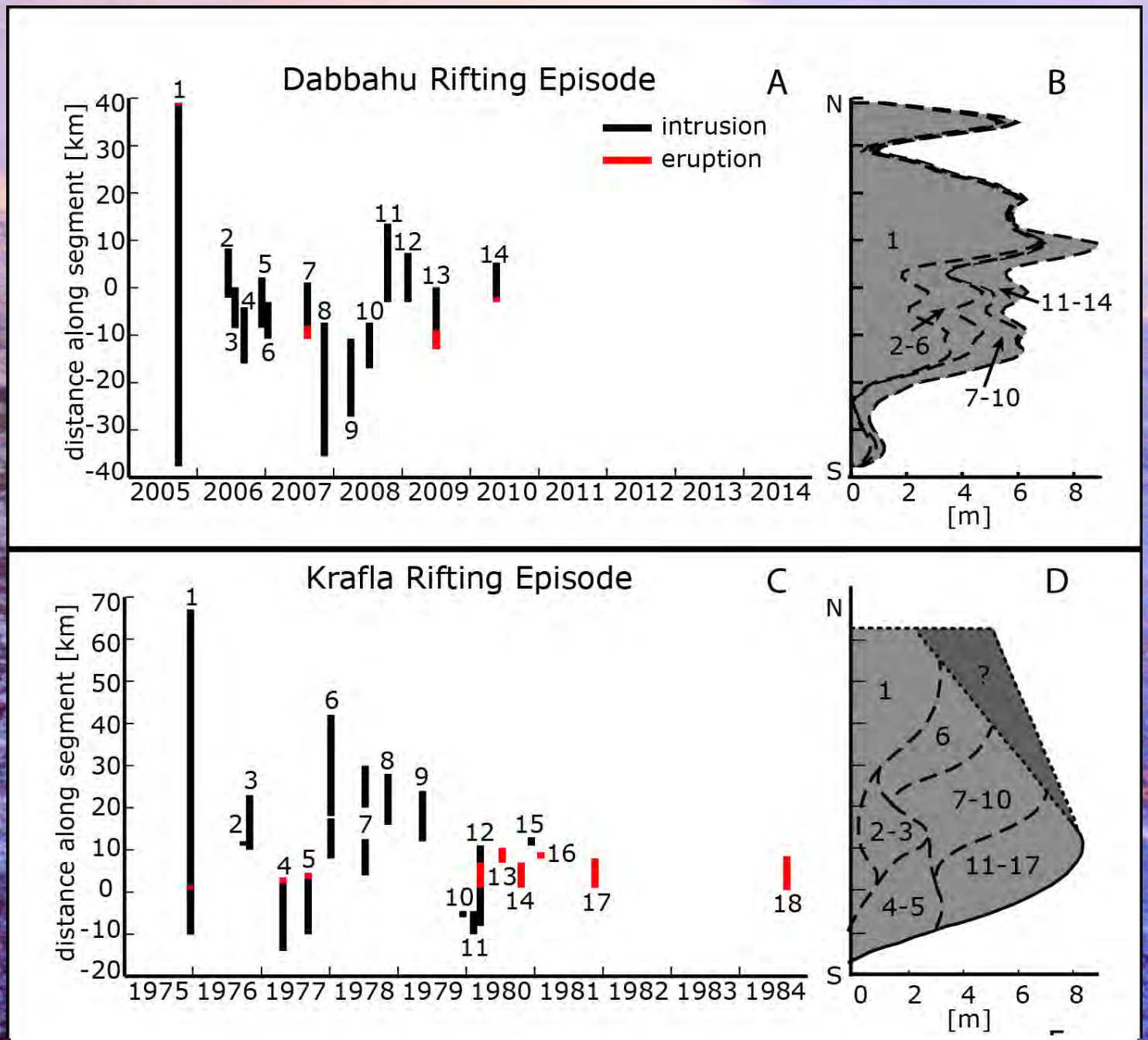


Post-intrusion deformation – Track 300



Post-intrusion deformation – Track 300



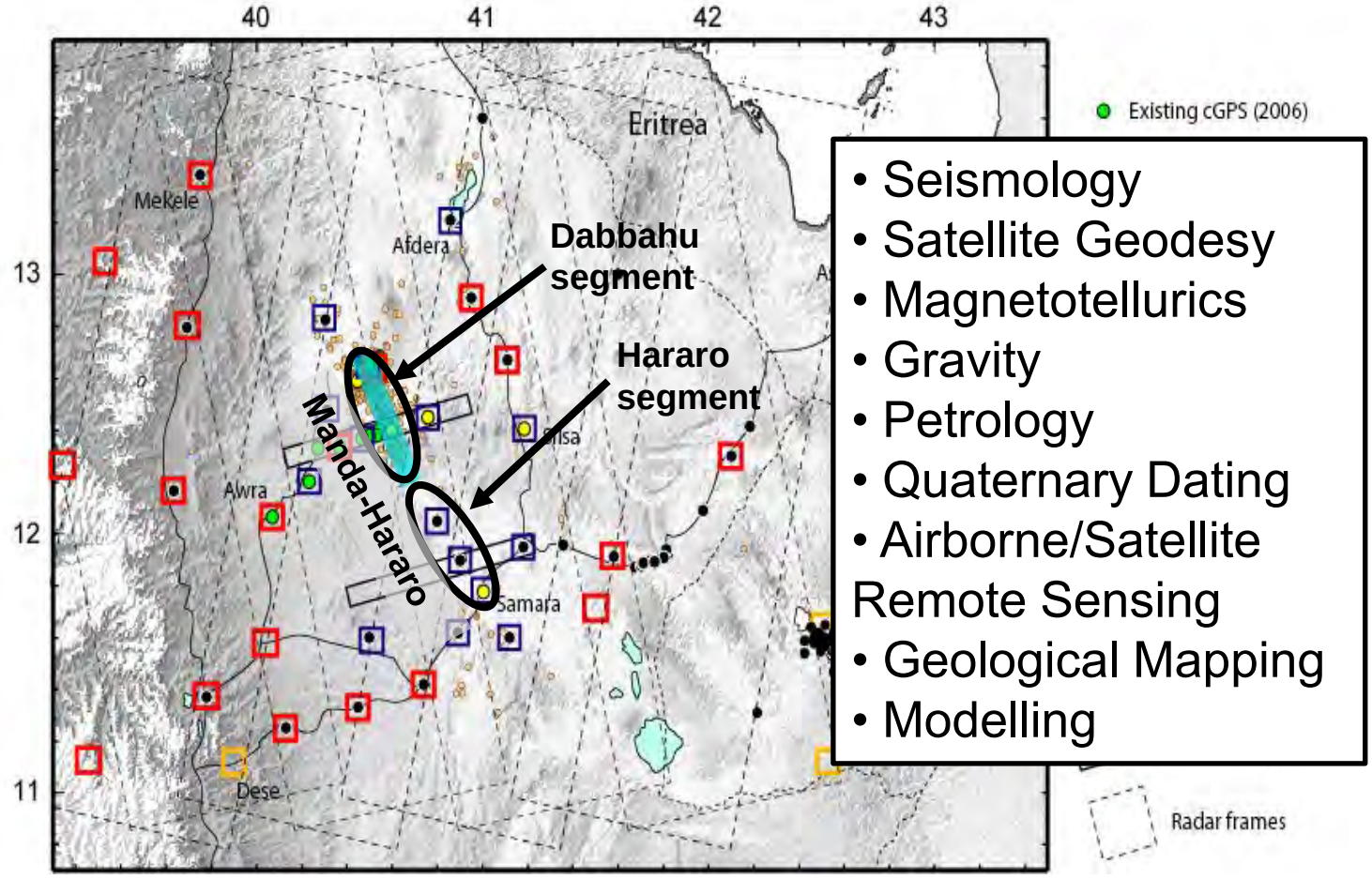


Wright, Sigmundsson et al., Nature Geosci., 2012

1977

The Afar Rift Consortium

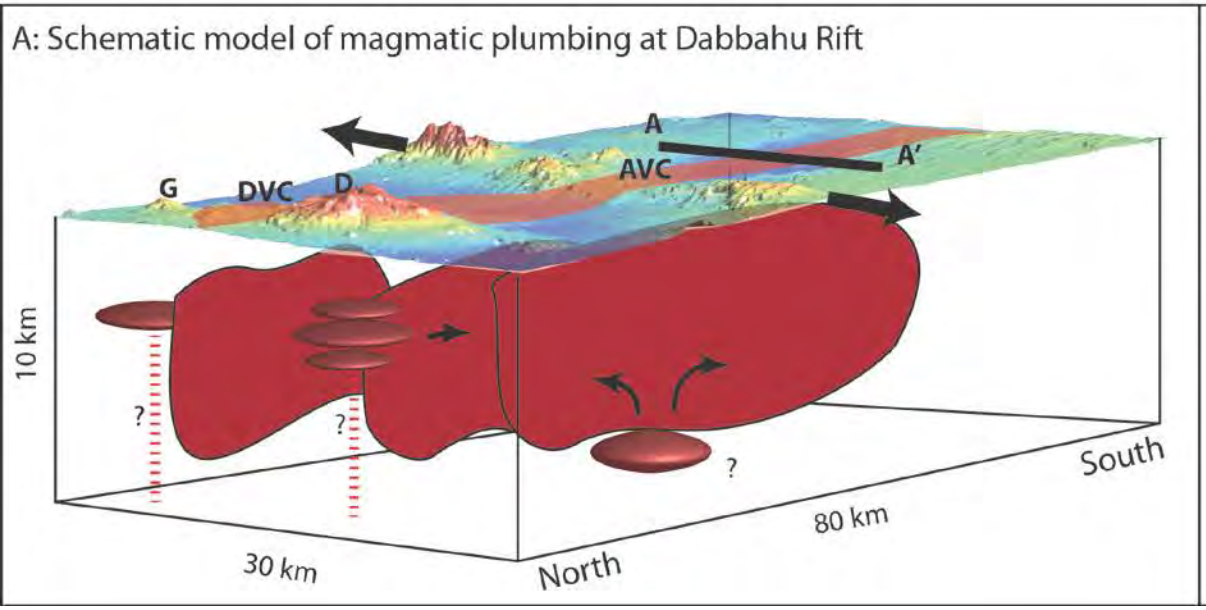
http://www.see.leeds.ac.uk/afar

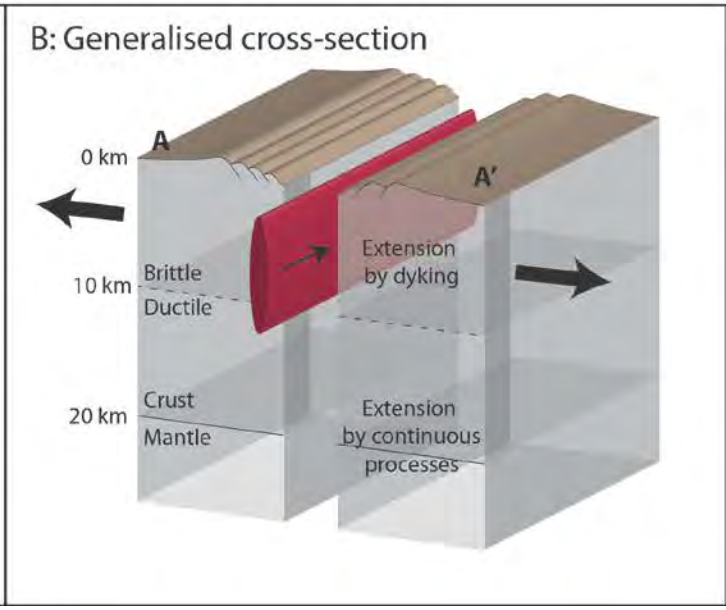


- Seismology
- Satellite Geodesy
- Magnetotellurics
- Gravity
- Petrology
- Quaternary Dating
- Airborne/Satellite Remote Sensing
- Geological Mapping
- Modelling

Fast and Furious: Witnessing the Birth of Africa's New Ocean.

Magmatic Plumbing at Dabbahu





- Brittle Upper Crust: extension occurs by episodic dyking, intruded laterally
- Ductile Lower Crust and Mantle: extension by continuous processes
- Shallow magma plumbing system is complex

Wright, Sigmundsson et al., Nature Geosci., 2012

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
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