30 years of postseismic deformation of a continental normal fault, measured by multi-satellite InSAR time-series
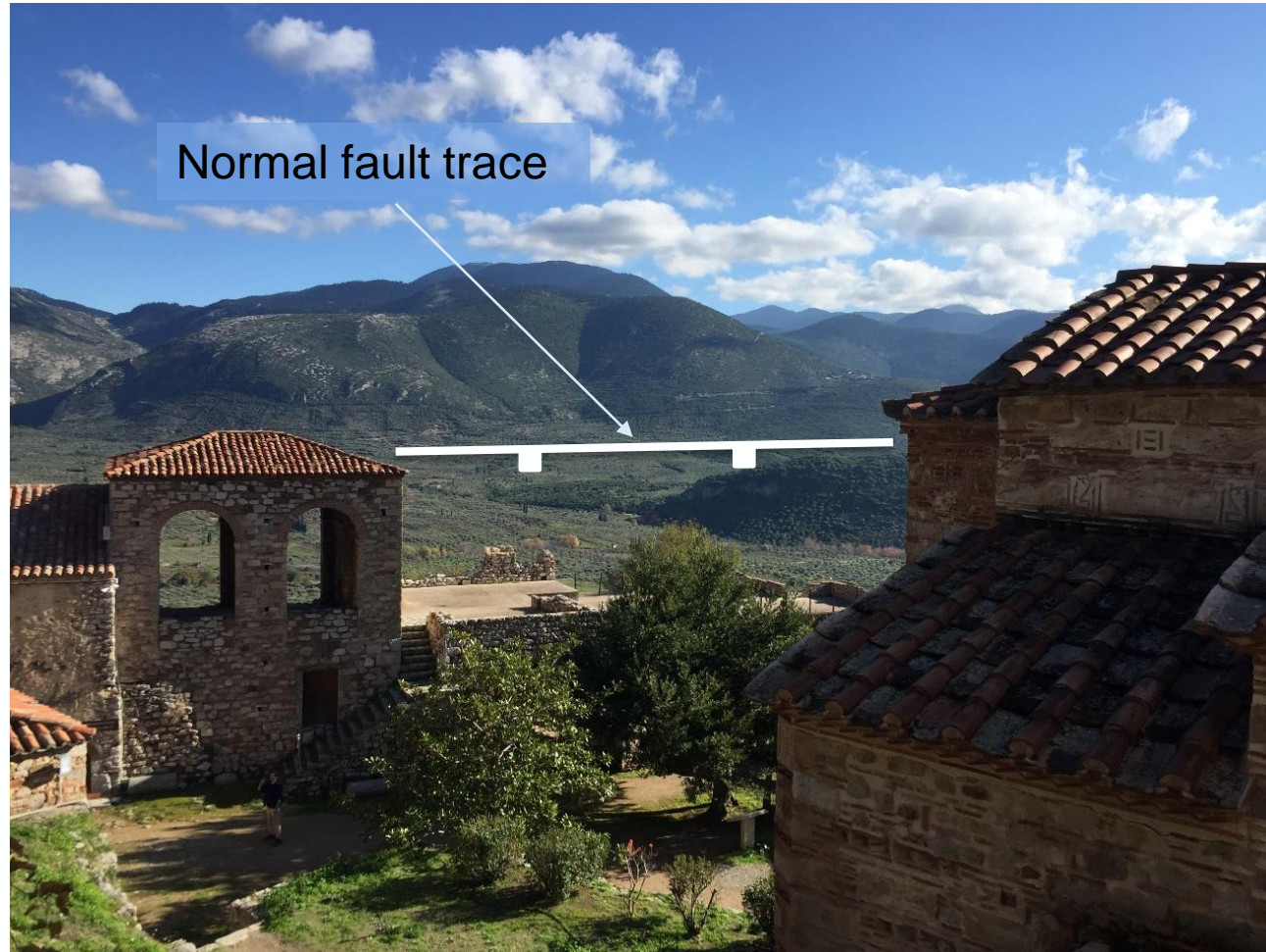
Natalie Forrest[1] , Tim Craig[1], Tim Wright[1], Laura Gregory[1], Ekbal Hussain[2], Alex Copley[3], Milan Lazecky[1]

[1]University of Leeds, [2]BGS, [3]University of Cambridge

FRINGE 2023
University of Leeds: 11th -15th Sep 2023

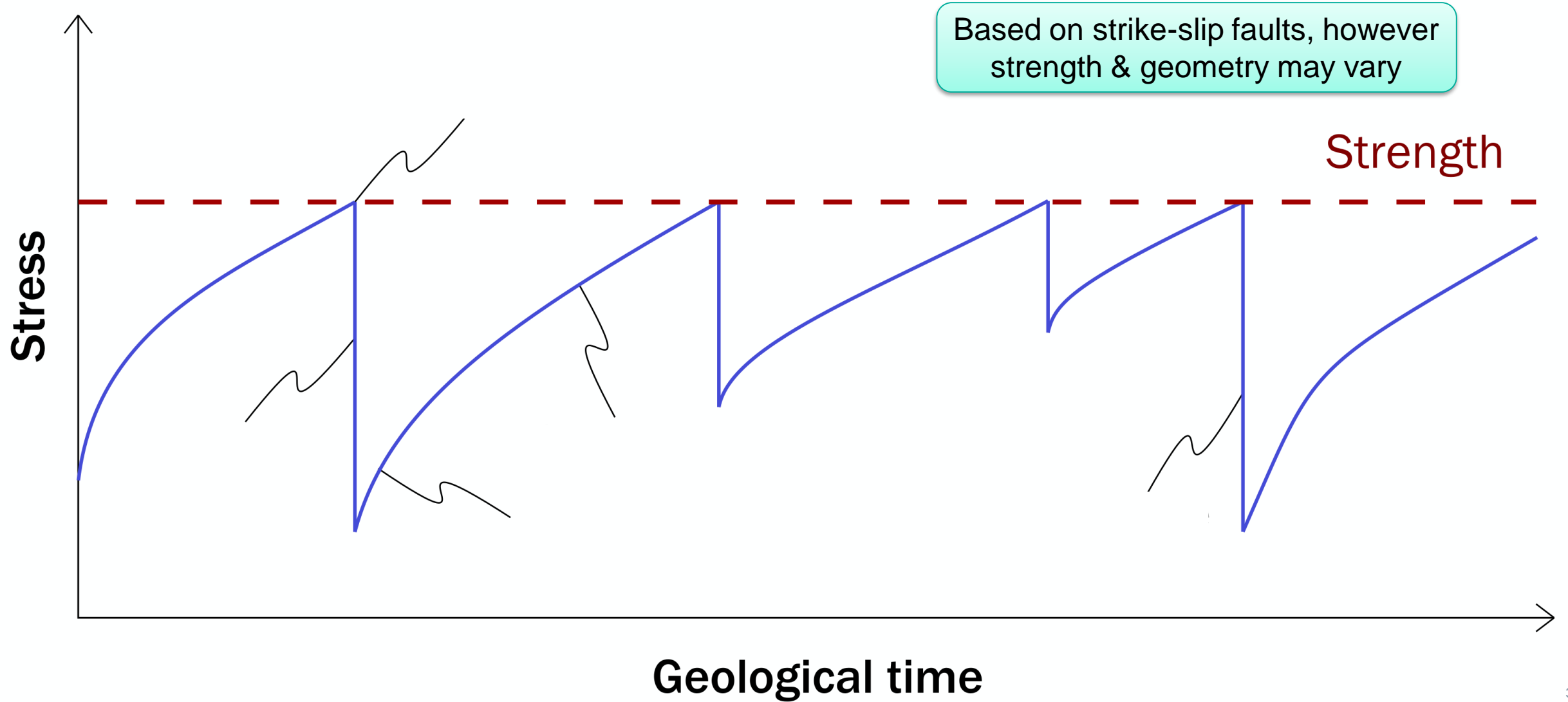→ THE EUROPEAN SPACE AGENCY

Example normal faults in the field

Normal fault trace

Normal fault in Gulf of Corinth, Greece

Normal fault offset in 2016 Central Apennines, Italy earthquakes (from Laura Gregory)

2016/11/01 15:50

A simplified earthquake cycle model

Based on strike-slip faults, however strength & geometry may vary

Strength

Stress

Geological time

Earthquake cycle models are based on strike-slip faults

Brittle regime: frictional sliding on the fault

Ductile regime: Weak zone embedded in a stronger substrate

Labels in figure: Aseismic Slip, Seismic rupture, Viscous Flow, 15 km, 30 km

Strike slip faults:
1. Have constant, simple geometry
2. Host large earthquakes (Mw < 8+)
3. Have fast slip rates (10^1 mm/yr)

Do earthquake cycle models also apply to dip-slip faults?

Figure adapted from Burgmann, 2018

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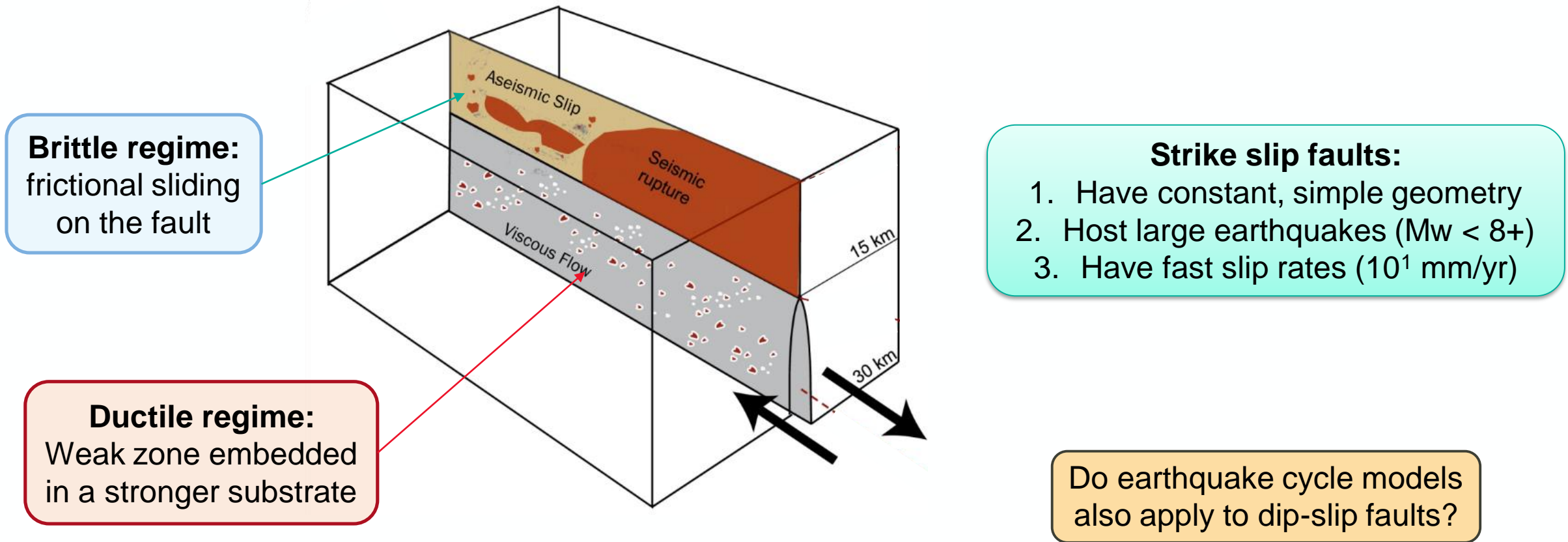
Aim of the project: study normal fault dynamics

Concepts about earthquake cycle (from strike-slip faults)

+
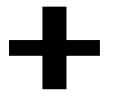
Thirty years of geodetic observations
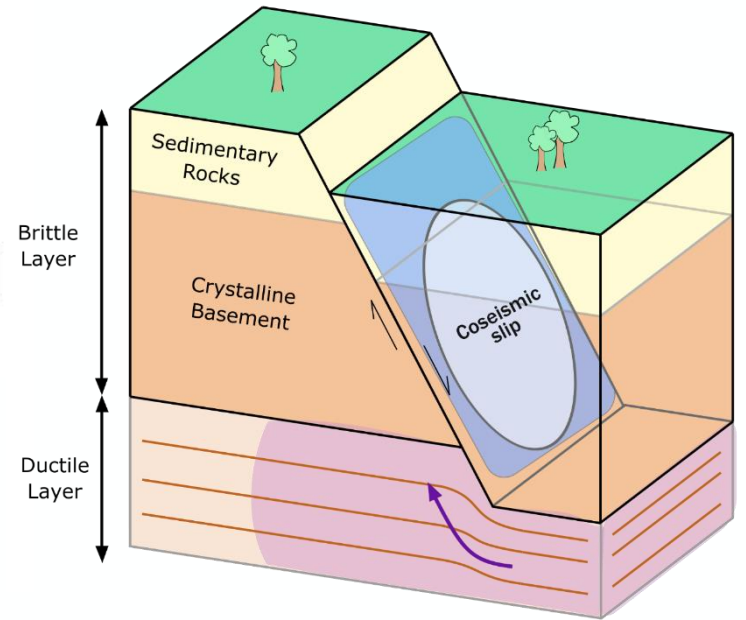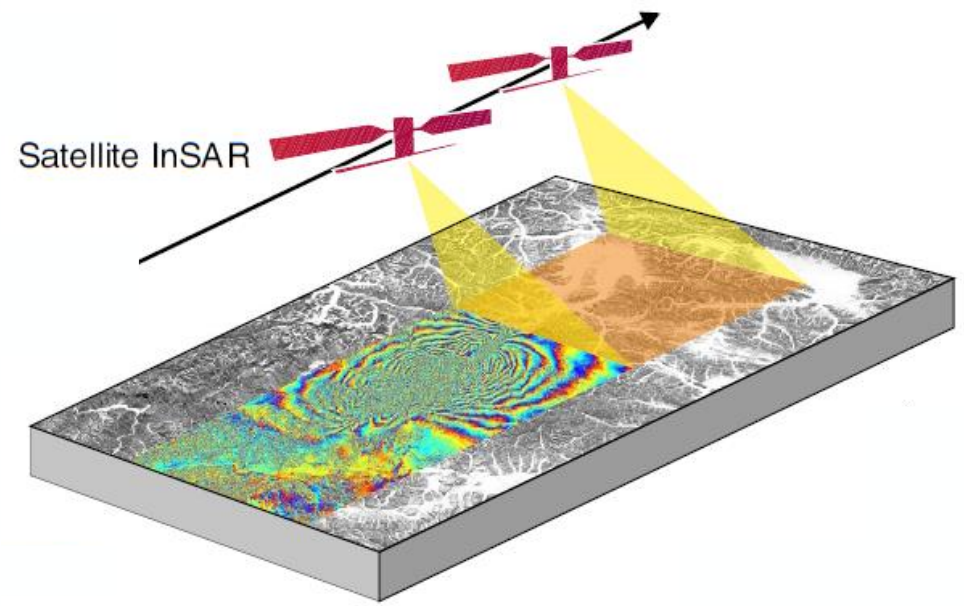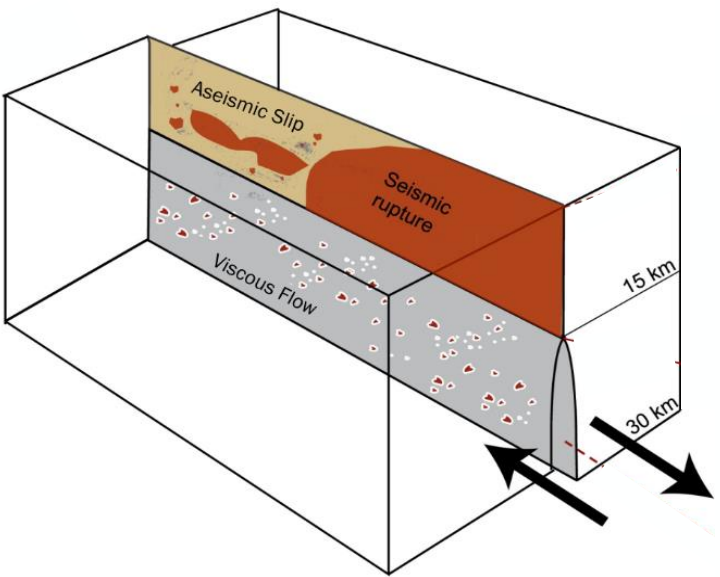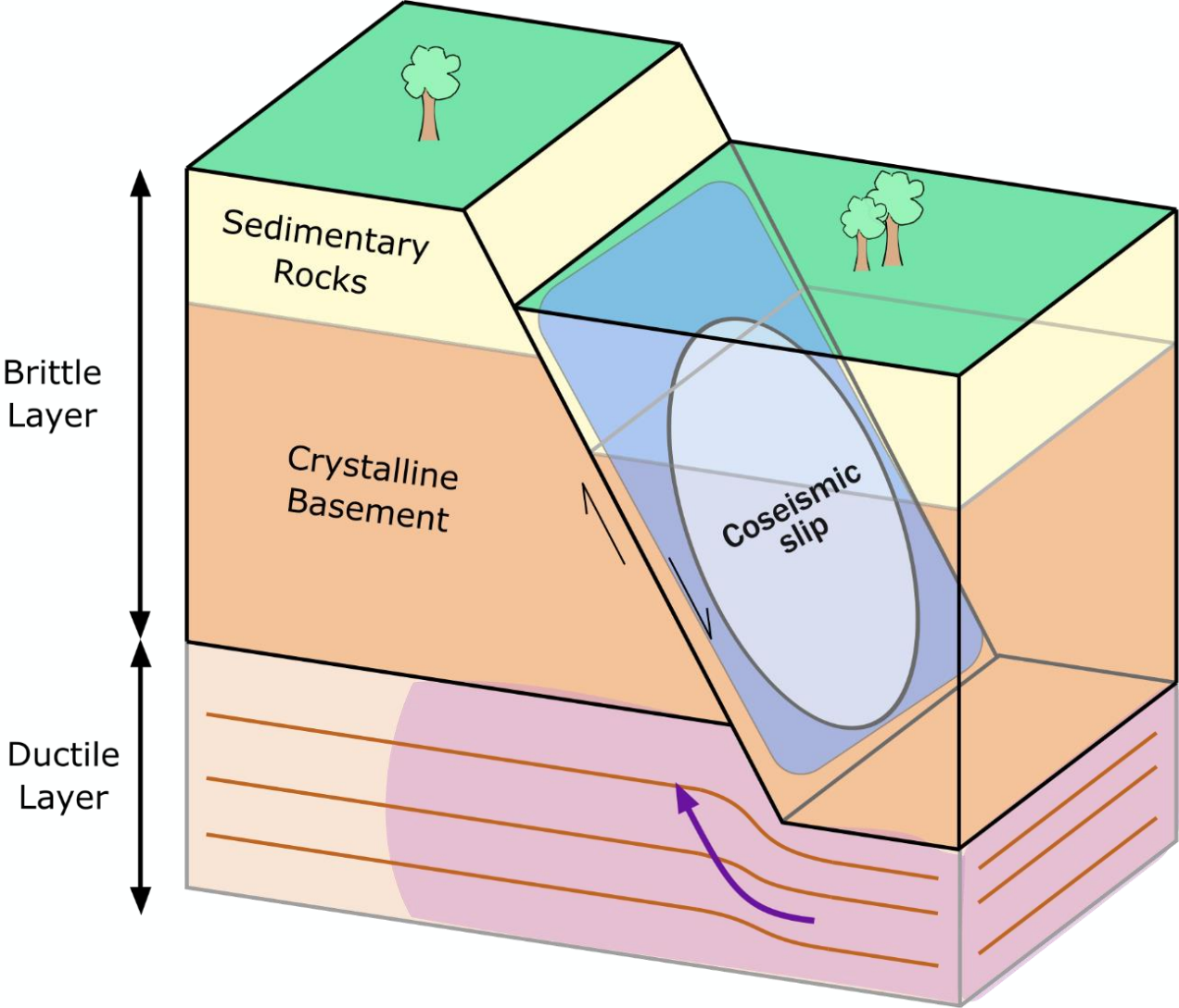
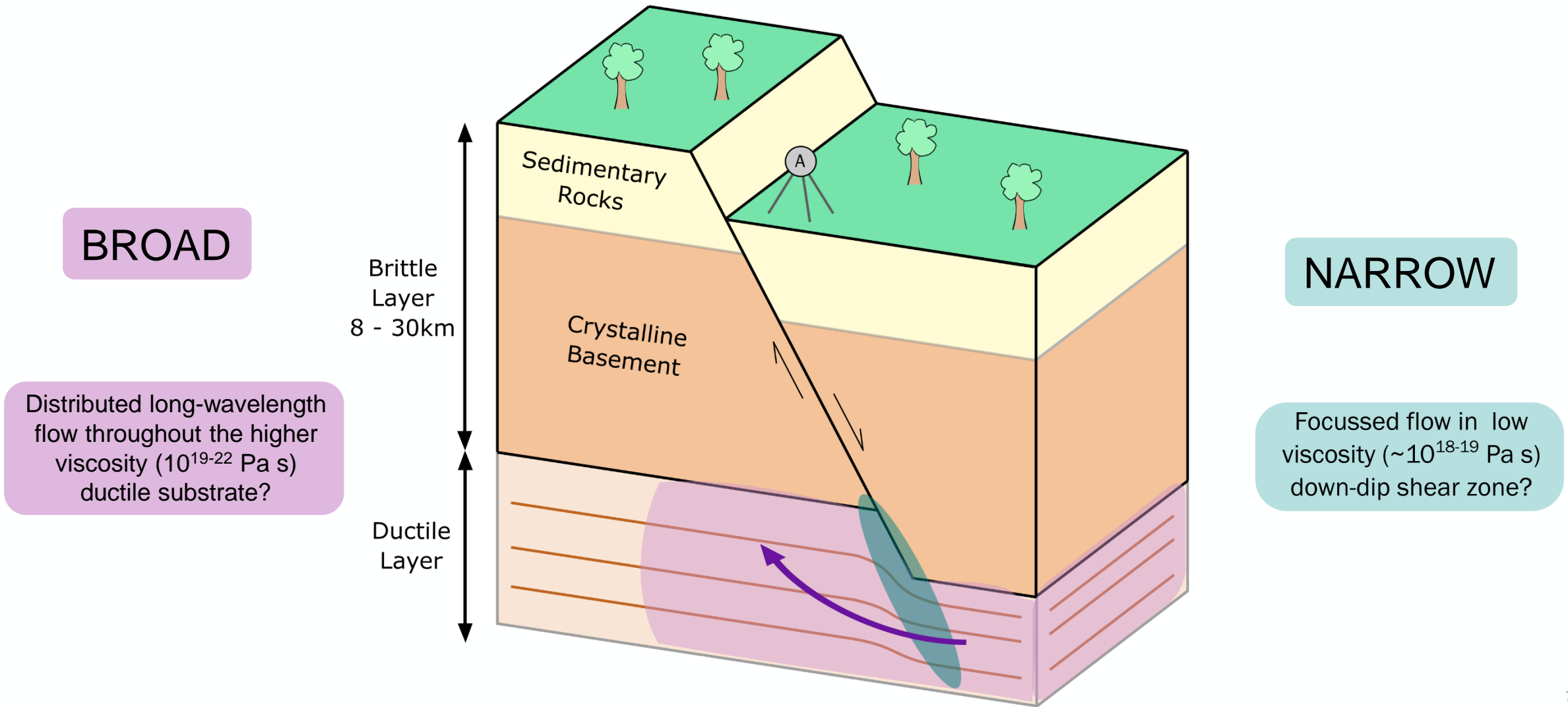**To better understand normal fault dynamics**

Figure adapted from Bürgmann, 2018
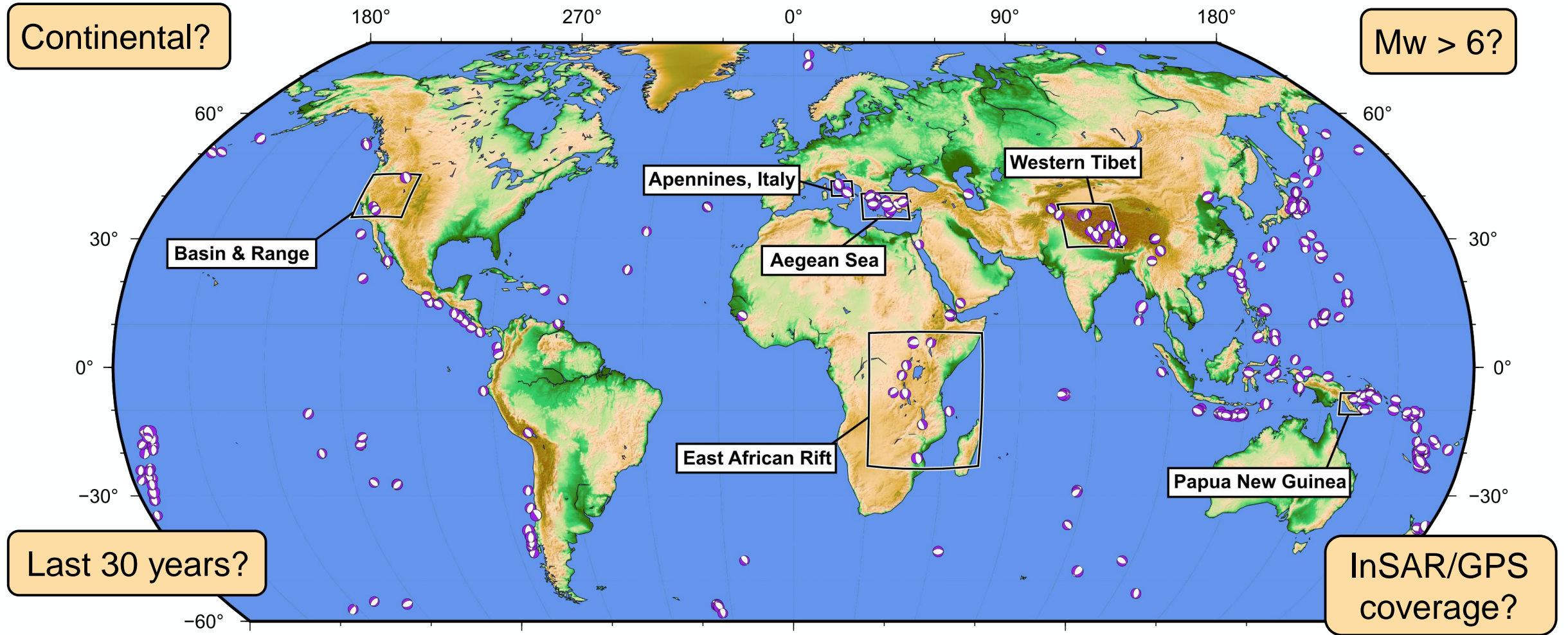
Figure adapted from Elliott et al, 2016

There are two primary postseismic mechanisms

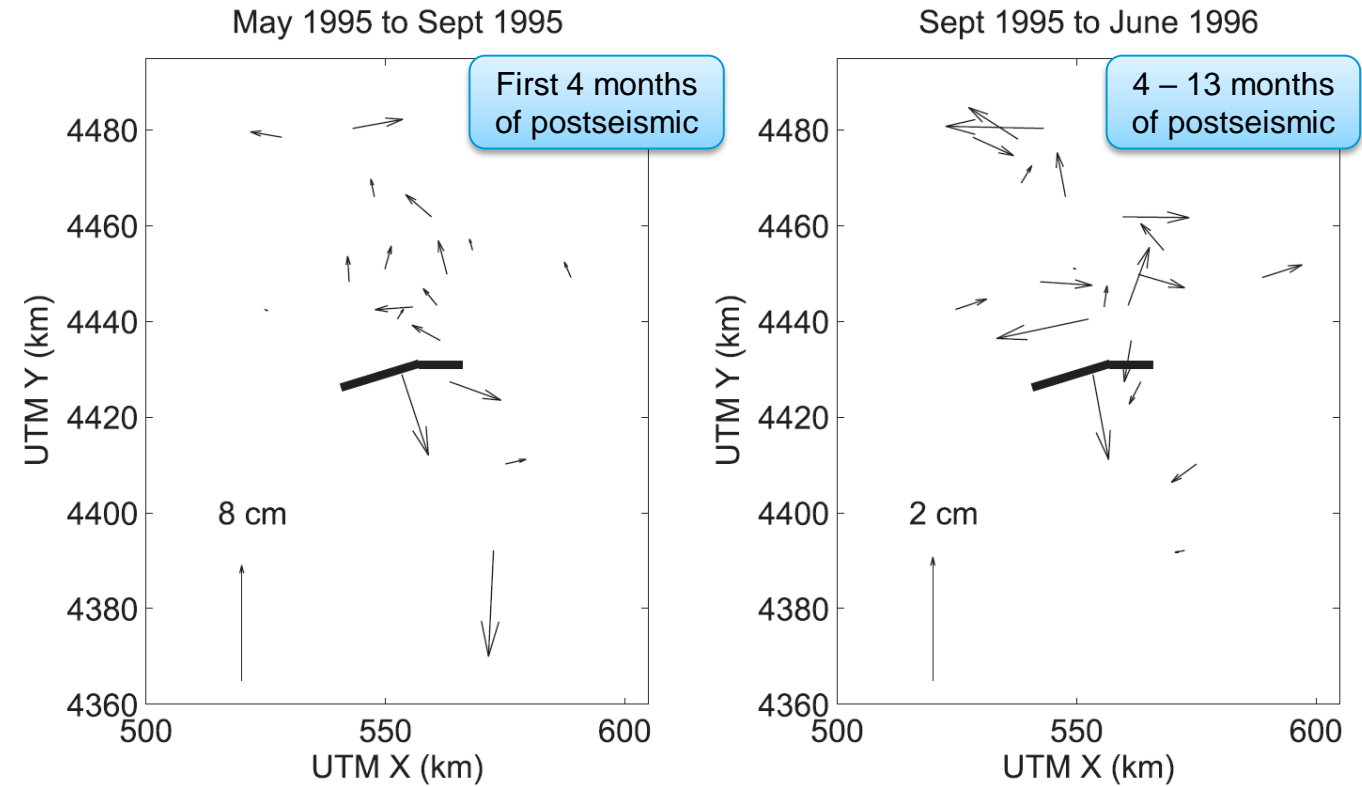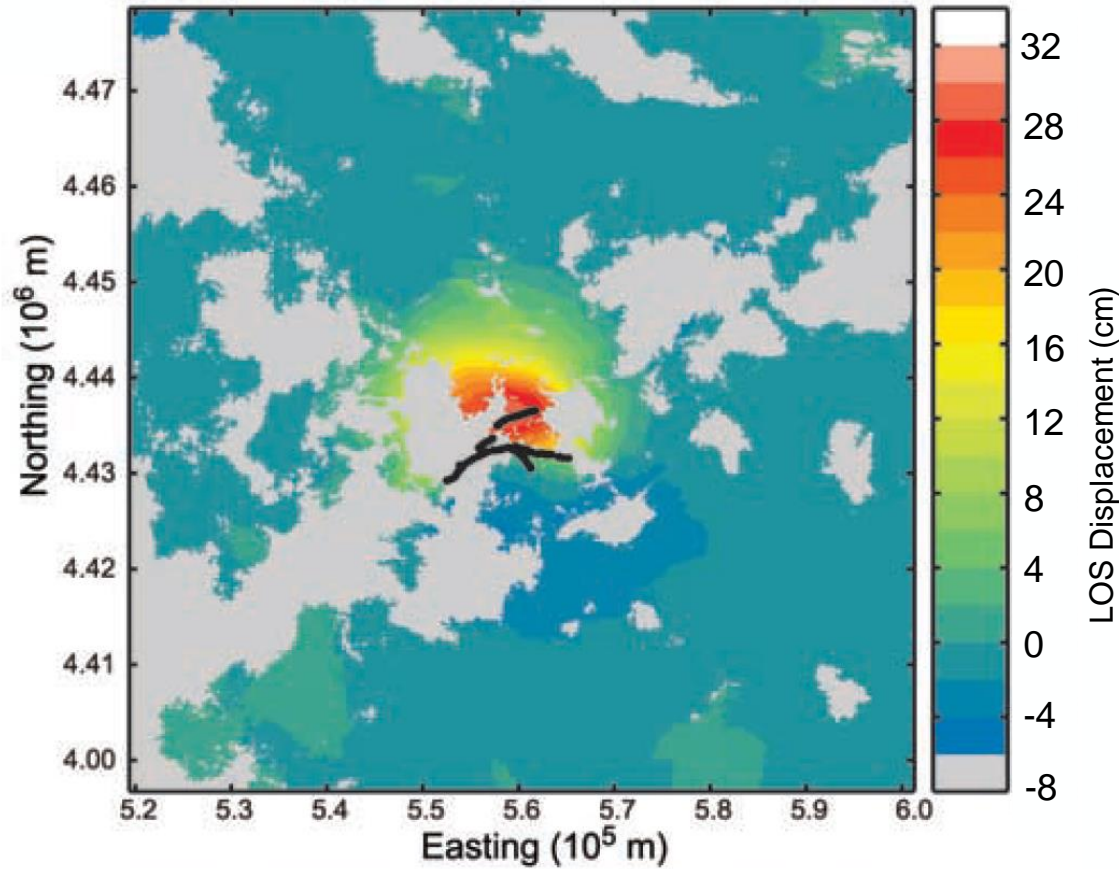# Two end-member models of viscoelastic relaxation

BROAD

Distributed long-wavelength flow throughout the higher viscosity (10^{19-22} Pa s) ductile substrate?

NARROW

Focussed flow in low viscosity (~10^{18-19} Pa s) down-dip shear zone?

Brittle Layer 8 - 30km

Ductile Layer

Sedimentary Rocks

Crystalline Basement

→ THE EUROPEAN SPACE AGENCY

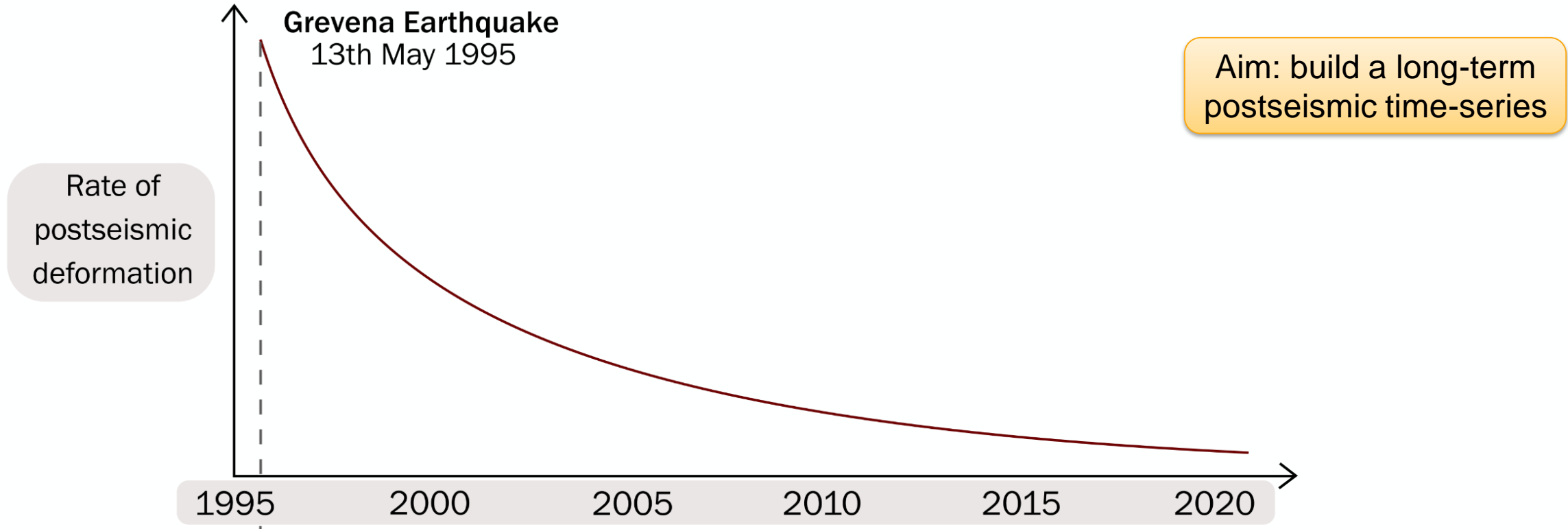# Selection criteria for choosing normal faults to study

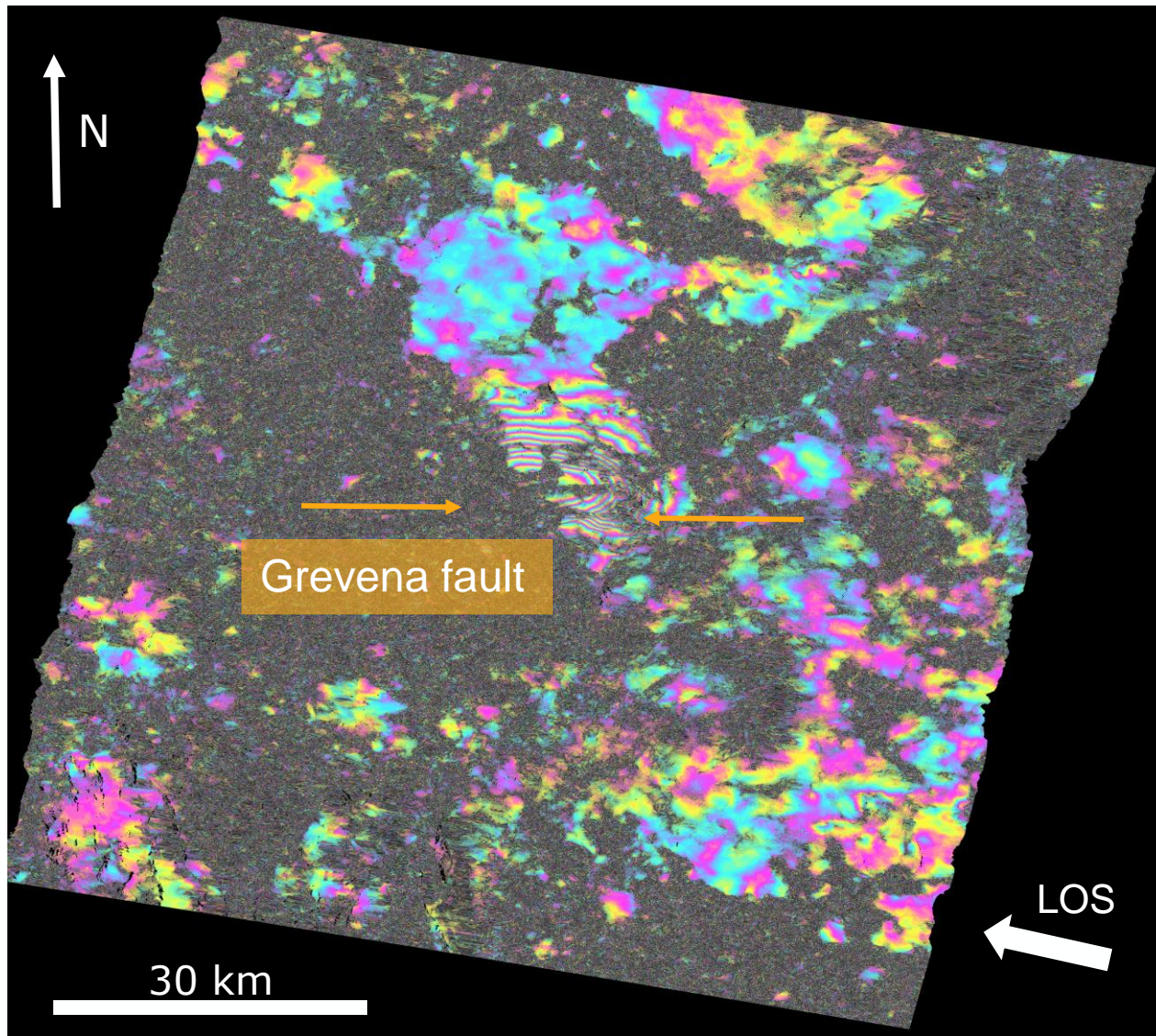First year of postseismic deformation measured during GPS campaign, from **Ryder (2006)**

Coseismic studies: Main fault strikes 243º WSW, dip 43º, rake ~-90º, 1-2 m slip from 6 – 15 km, from **Resor et al, 2005**

Previous studies focus on early postseismic (5 yrs), but now data are available for nearly 30 yrs

Conceptual timeline of Grevena postseismic deformation

Grevena Earthquake
13th May 1995

Rate of postseismic deformation

Aim: build a long-term postseismic time-series

1995   2000   2005   2010   2015   2020

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Coseismic interferogram for Grevena earthquake
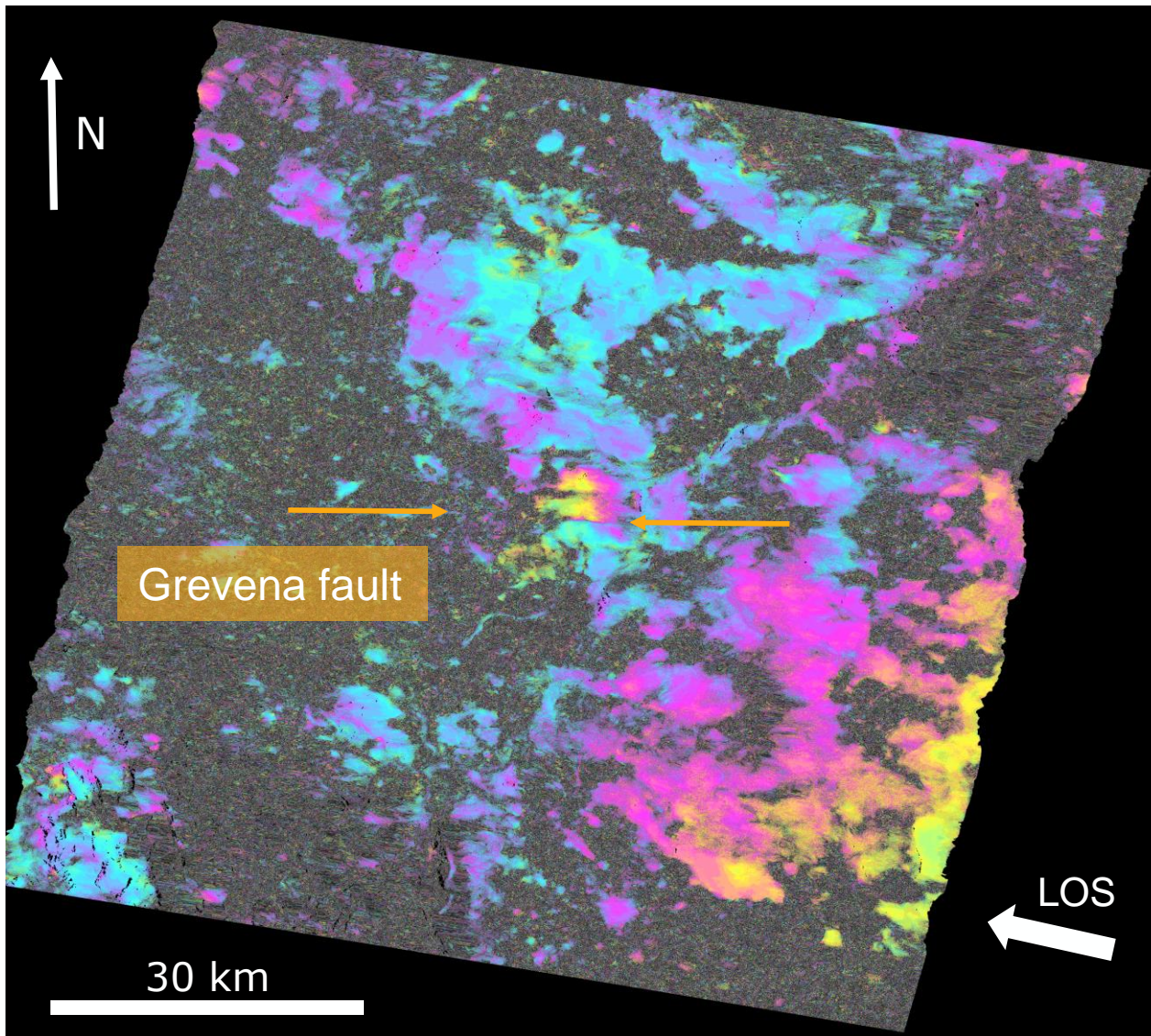

**Grevena Mw 6.5
13/05/1995**

ERS 29/06/1993 to 01/09/1995

Coseismic & 3.5 months postseismic

N-dipping normal fault

12 fringes ≈ 35 cm LOS displacement

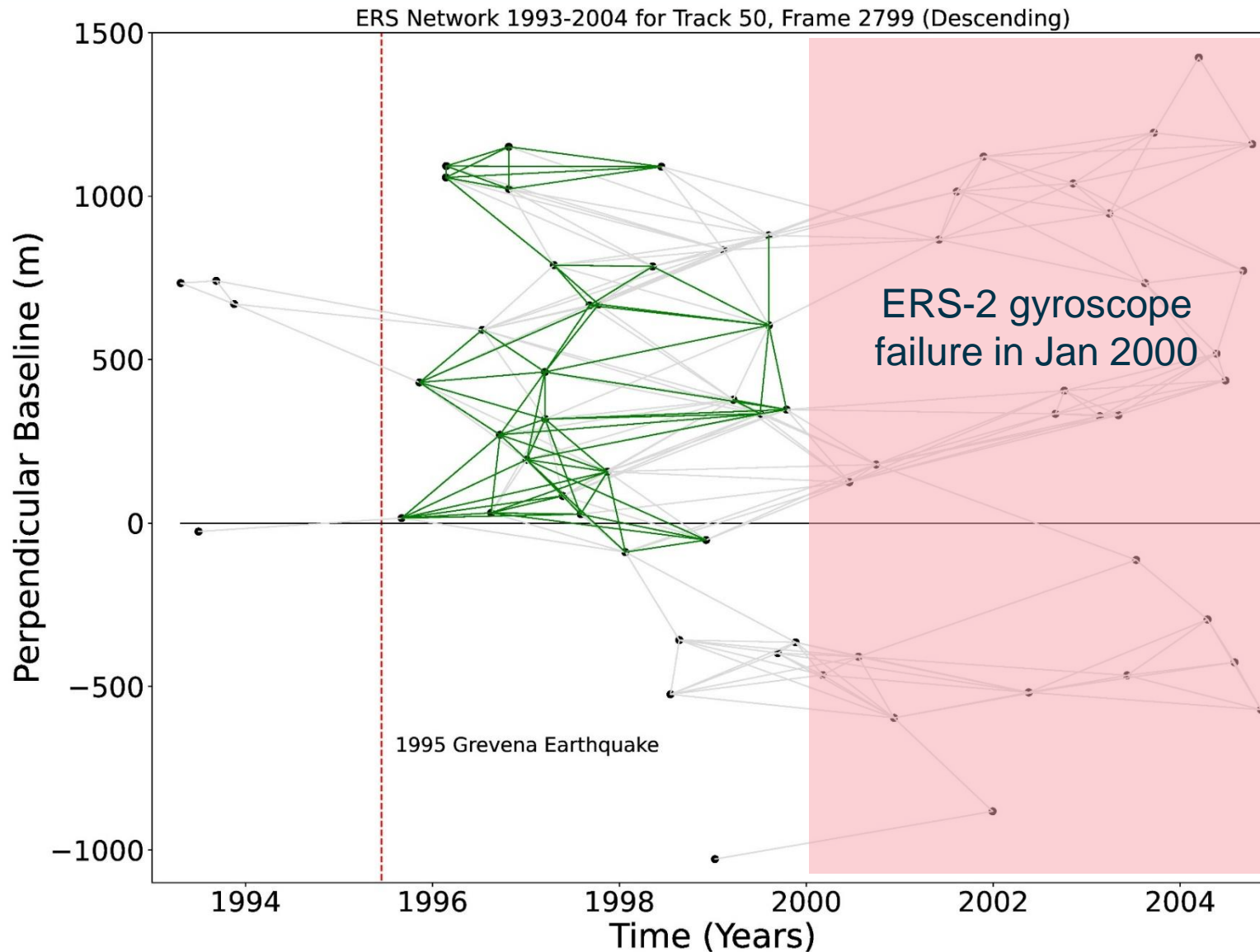# ERS interferograms show early postseismic displacement

**Grevena Mw 6.5
13/05/1995**

ERS 10/11/1995 to 13/03/1997

6 to 22 months after the earthquake

1.5 fringes ≈ 4 cm LOS displacement

1. Sharp interface
2. Lengthscale ~10km
3. Afterslip

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Building an ERS postseismic time-series network

ERS Network 1993-2004 for Track 50, Frame 2799 (Descending)

Temporal baseline < 3 years

Spatial baseline < 300 m

ERS-2 gyroscope failure in Jan 2000

67 interferograms into StaMPS

Reduce noise, increase coherence

1995 Grevena Earthquake

→ THE EUROPEAN SPACE AGENCY

Sep 1995 to Nov 1999
4 months to 4.5 years
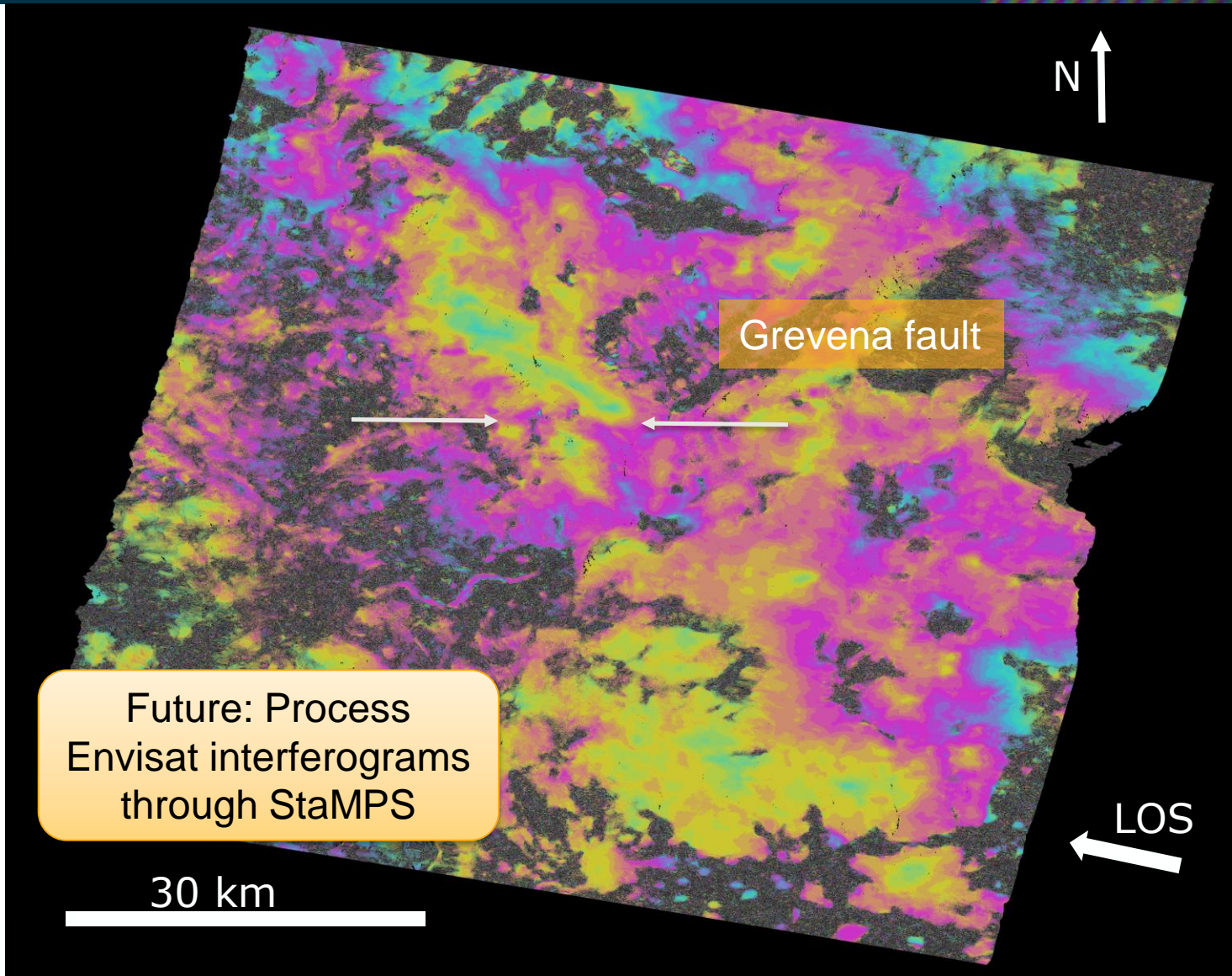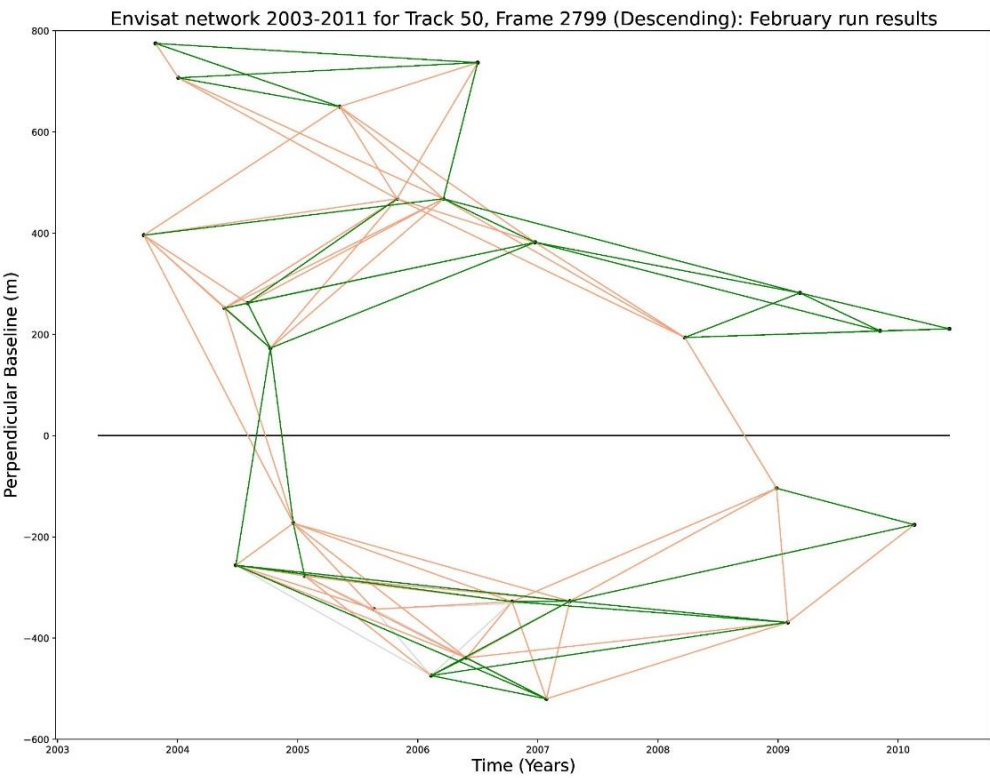after the earthquake

Sharp interface

Deformation
extends 15 - 20 km
from fault

Combination
afterslip & VE?
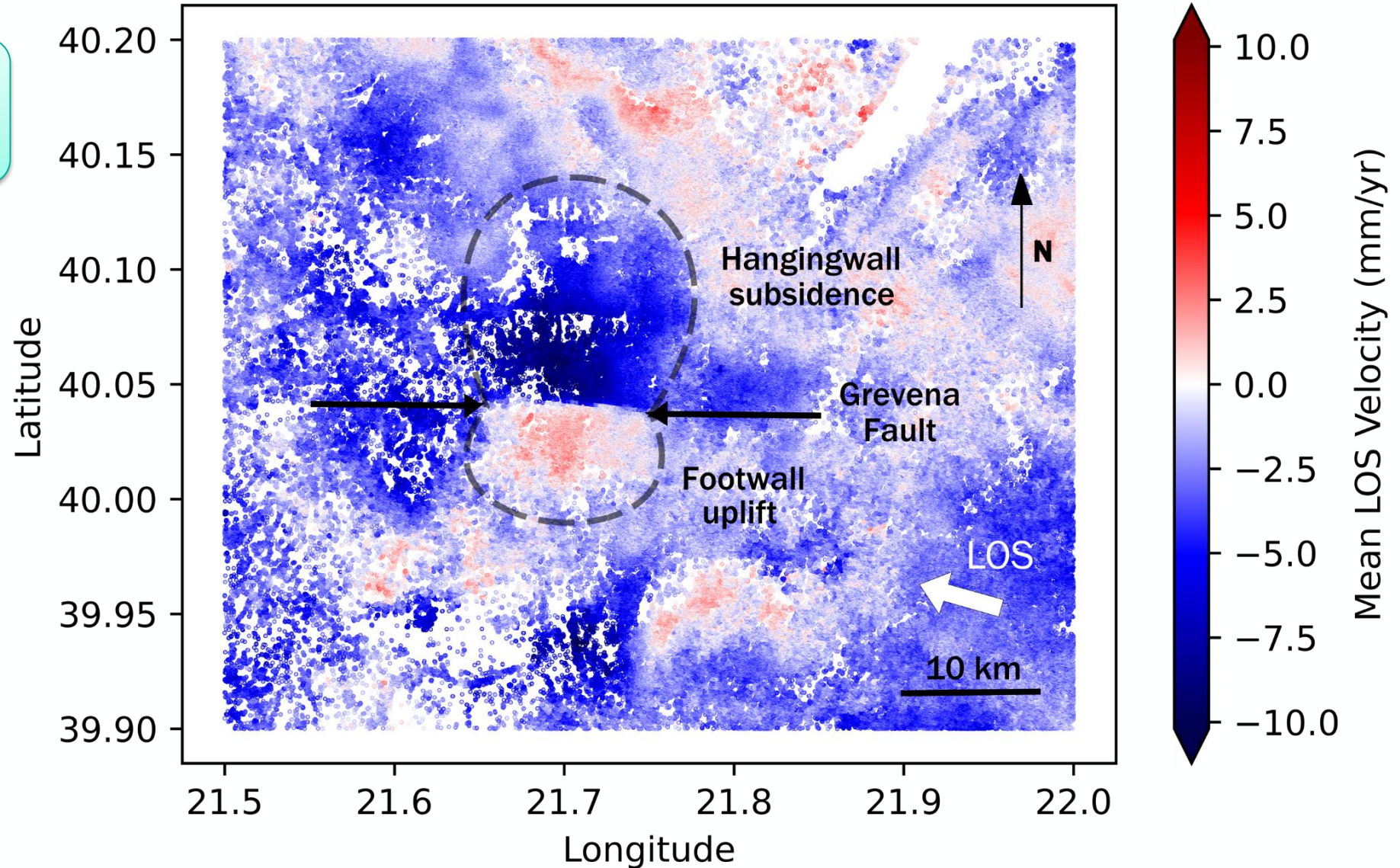
Constructing the Envisat postseismic time-series

13 Oct 2006 to 6th April 2007
11.5 to 12 years after the earthquake

Envisat network 2003-2011 for Track 50, Frame 2799 (Descending): February run results

N

Grevena fault

Future: Process
Envisat interferograms
through StaMPS

LOS

30 km

Sentinel-1: LiCSBAS doesn't show any displacement

19.5 to 26.5 years after the earthquake

No measurable postseismic deformation around Grevena

Does this mean that postseismic deformation has finished?
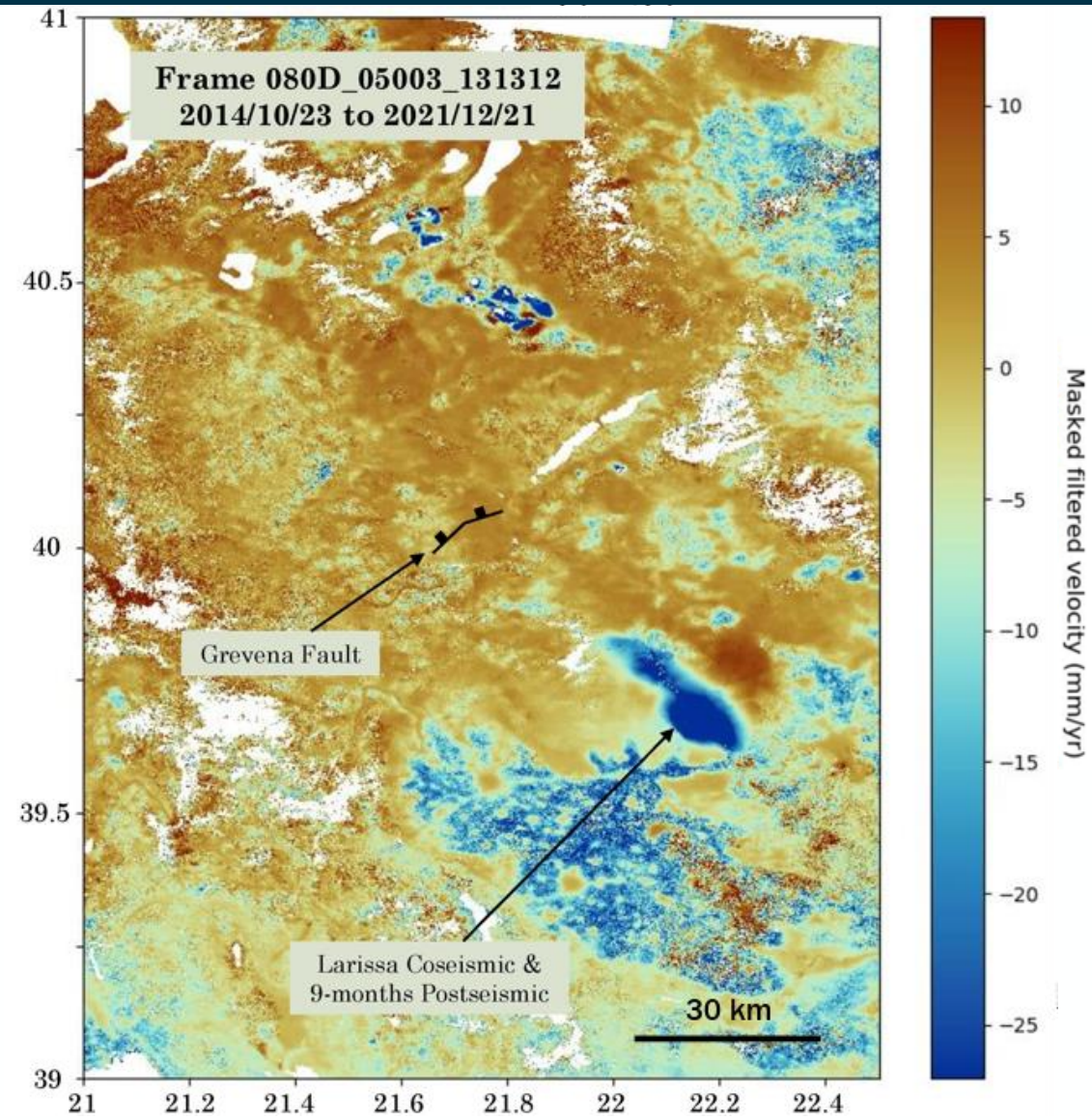
Would postseismic be observable 20 years later within uncertainties?

Sentinel-1: EGMS doesn't show any displacement

20.5 to 26.5 years after the earthquake (Jan 2016 to Dec 2021)

No measurable postseismic deformation around Grevena

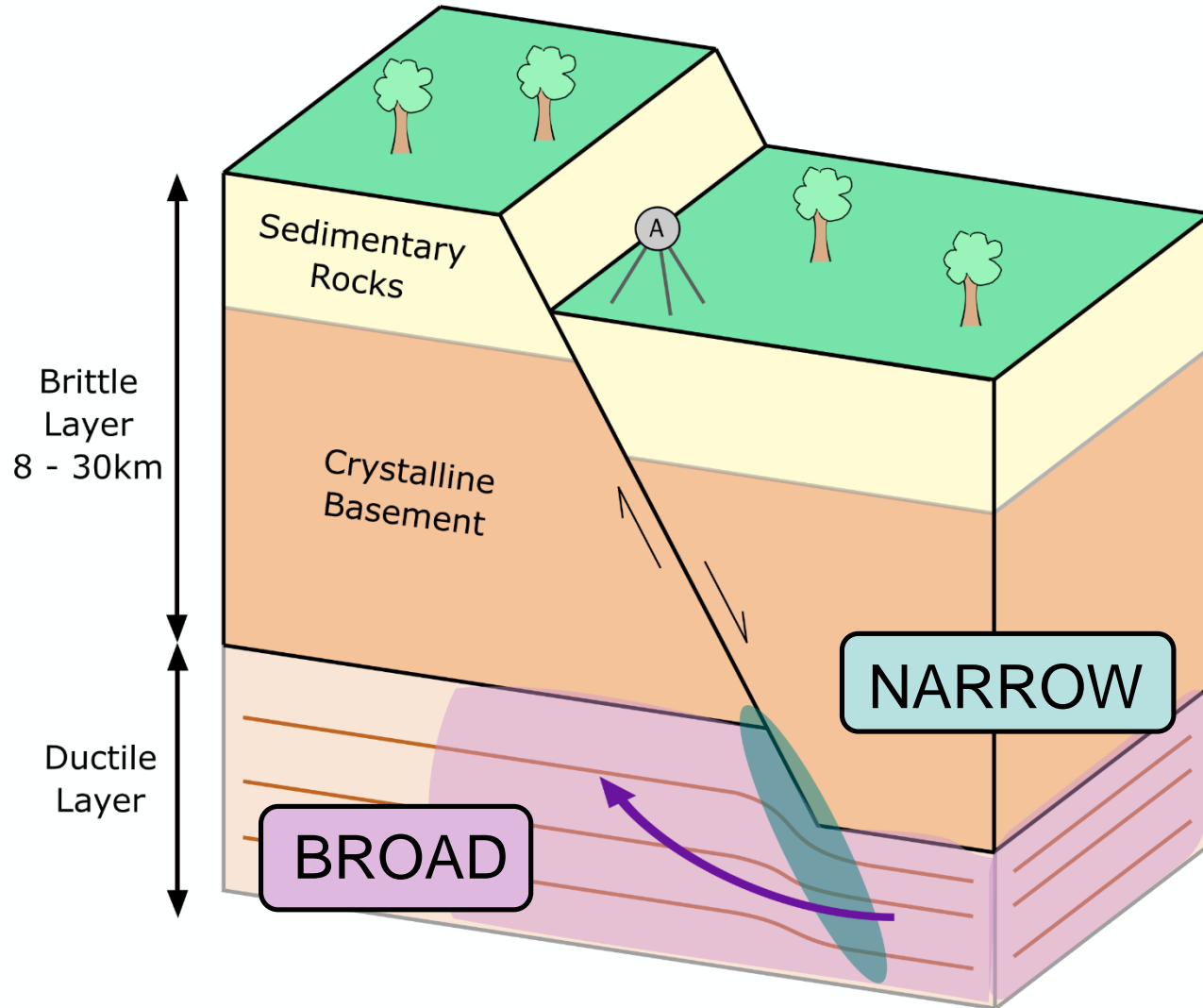Grevena fault

Does this mean that postseismic deformation has finished?

Would postseismic be observable 20 years later within uncertainties?
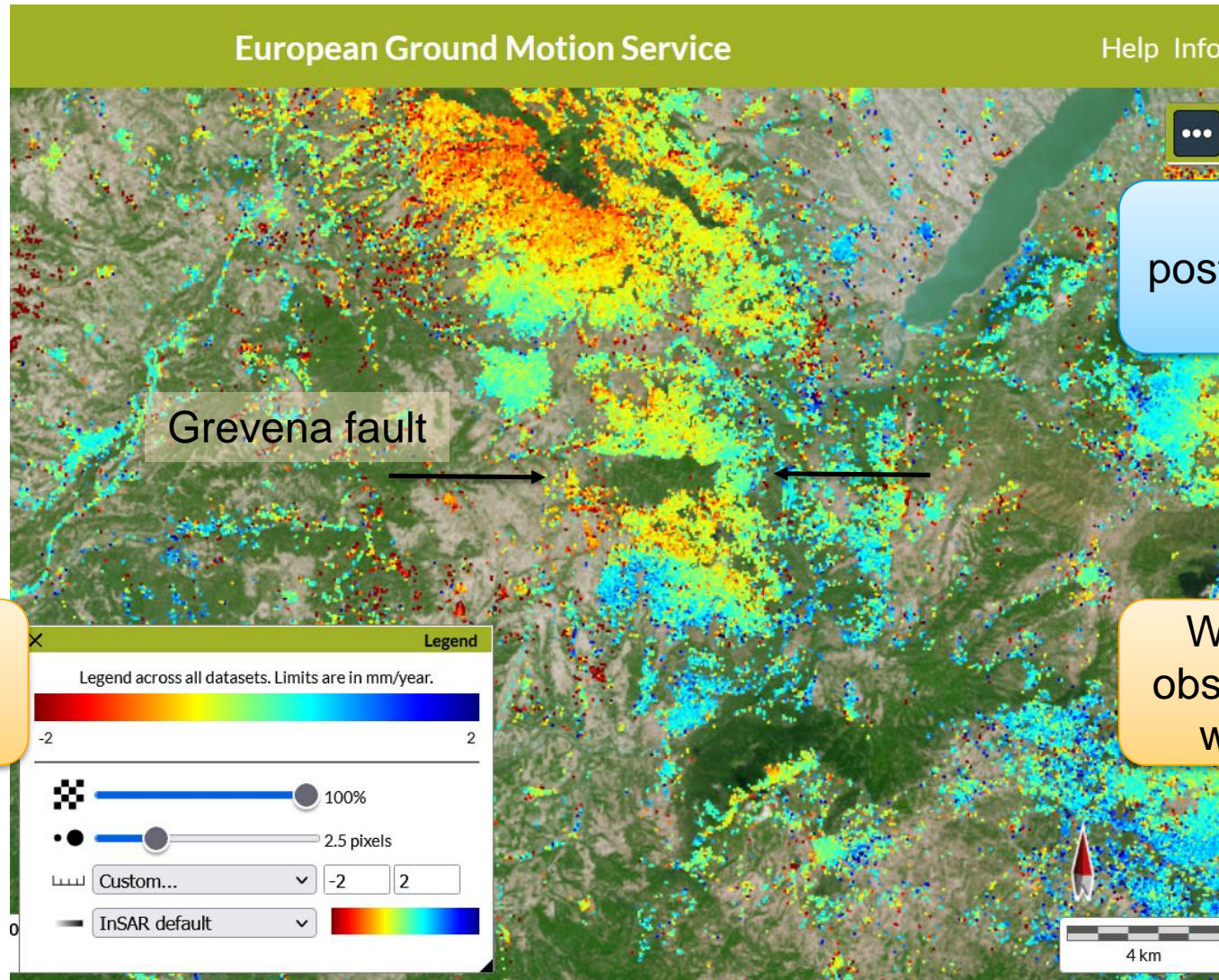
Bringing observations together
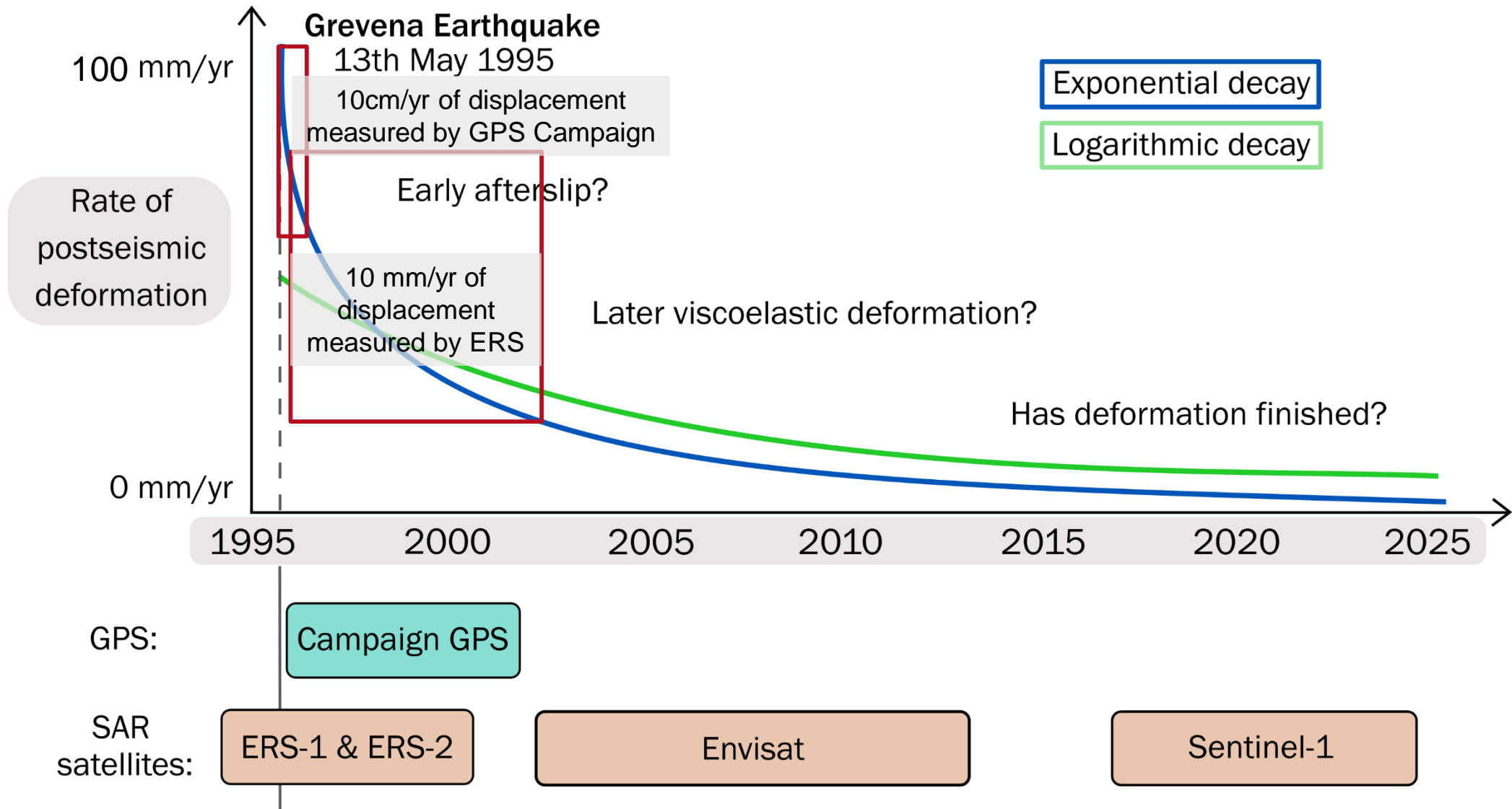
Three generations of SAR satellites measured postseismic deformation following Mw 6.5 Grevena earthquake

Generating 30 yr InSAR time-series, to interpret under-studied dip-slip fault dynamics

Next: Run forward models & compare with strike-slip faults

Sedimentary Rocks

Crystalline Basement

Brittle Layer 8 - 30km

Ductile Layer

NARROW

BROAD