Tectonic controls on the origin of buried hollows

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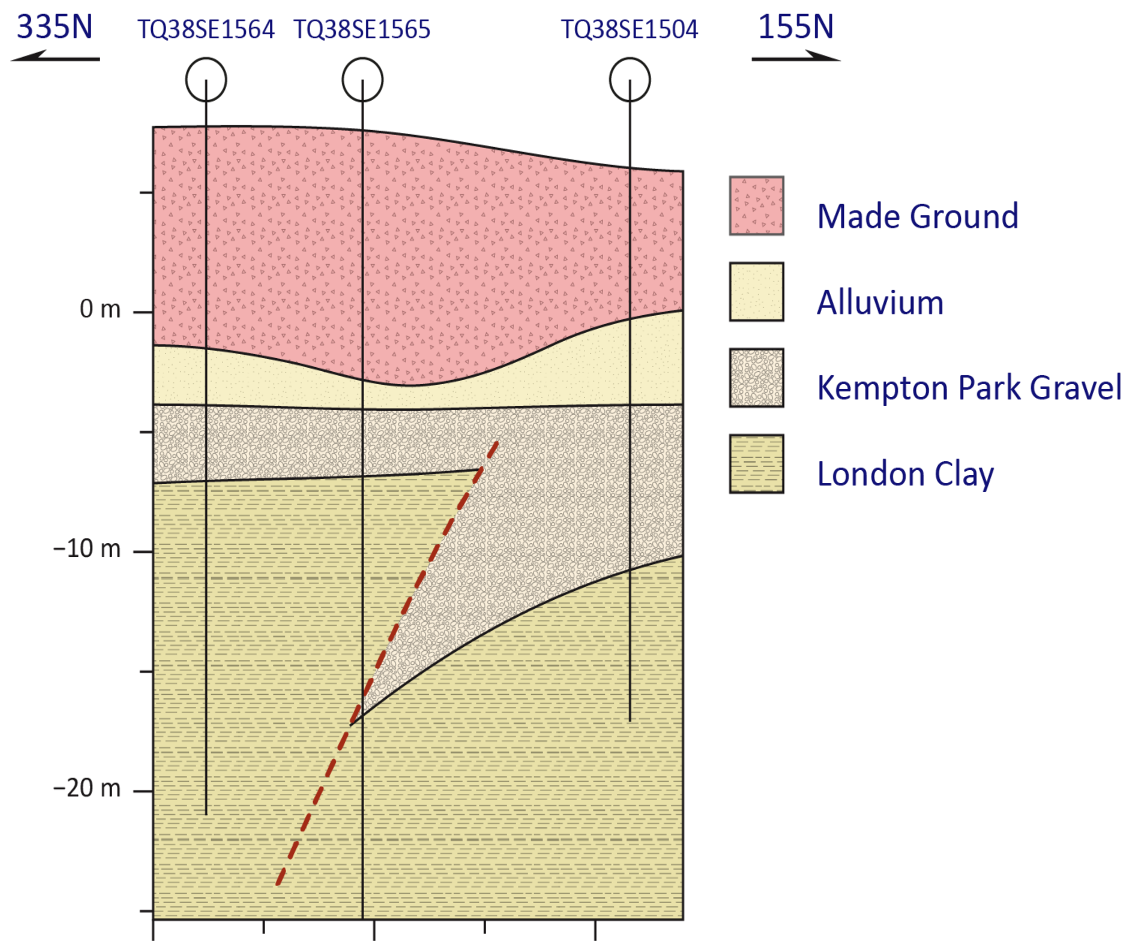
CGG Passion for Geoscience

Tectonic controls on the origin of buried hollows

- Drivers for this work
- The tectonic framework of London
- London PSI dataset, analysis and results
- How the faults and hollows are related
- What next?

Drivers? Expecting the unexpected

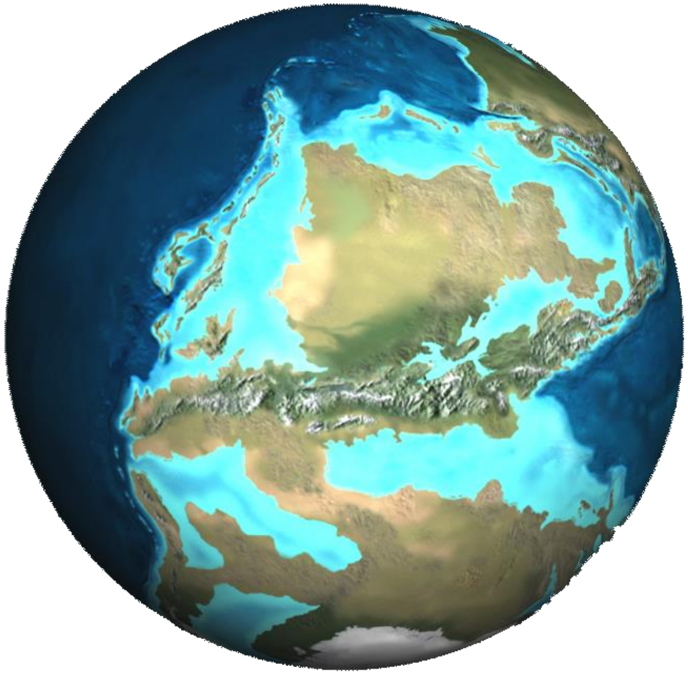
- Borehole TQ38SE1565 recorded a normal sequence of terrace gravels and London Clay to a depth of 15 m, and then a *repeated sequence* of terrace gravels and London Clay.
- Adjacent boreholes show nearly 10 m of reverse normal movement of London Clay *over* terrace gravels: gravels that are no more than 100 ka old.
- What caused of this displacement?



Tectonic Background

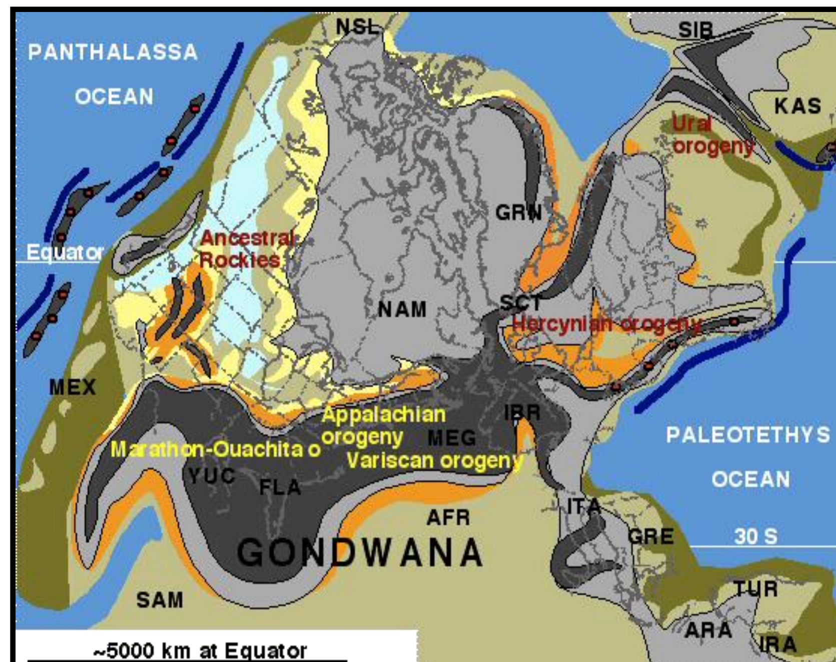
- To understand the complexities of the structure beneath the London Basin we need to consider its position and the tectonic evolution of the basement on which it sits
- Several important events dominate the brittle structures at depth which affect the basement, mainly these include:
  - The Variscan (Devonian to Carboniferous) and Alpine orogenies (Cretaceous — Tertiary).
- Both these need to be considered since brittle structures formed by each event and the impact they have on subsequent tectonic events.

Variscan Orogeny



The Variscan Orogeny that led to the formation of Pangaea 300 Ma ago during the Carboniferous generated an east–west thrust fabric and a SE-NW strike-slip fabric across southern Britain.

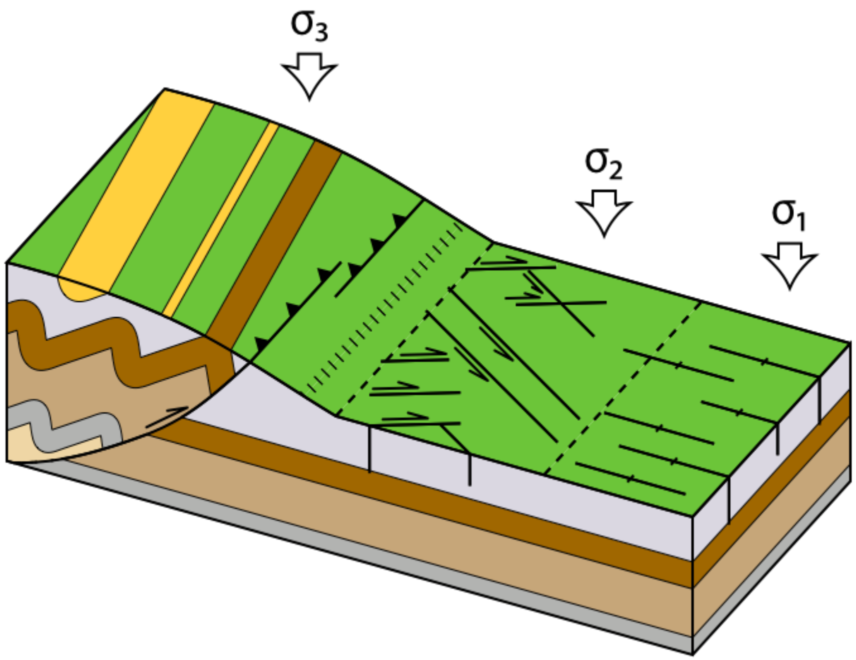
While the rocks formed deformed during this orogeny are now at a depth of several hundred metres, the structural fabric they contain still controls the tectonic behaviour of the rocks directly above.



Reconstruction by Ron Blakey

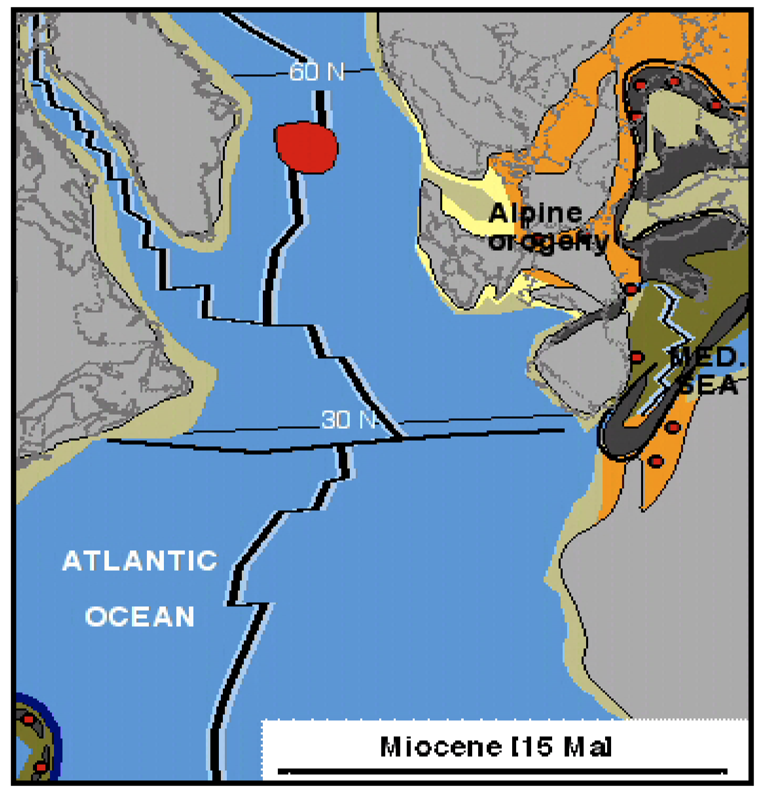
Stress Field Relaxation

- During thrusting, the horizontal (tectonic) compressive stress is much larger than the gravitational stress (overburden pressure), so that σ_1 is horizontal and σ_3 is vertical.
- Away from the active orogenic belt, the tectonic stresses are lower, such that the stress field reorients itself with first σ_2 vertical and finally to the normal condition in which σ_1 vertical.
- Given its location immediately north of the Variscan orogenic belt, we should expect strike-slip faults in the London Basin.



Alpine Orogeny

The Alpine Orogeny started in the Cretaceous with the closure of Tethys but has been a long, complex collision with fragments of both Europe and Africa splintering apart and colliding with the other.



Reconstruction by Ron Blakey

In the Miocene, however, a sustained northward push was experienced throughout western Europe, causing inversion of many basins to the north of the Alps.

Neogene Activity

- Although a few estuarine sediments are known from the Oligocene and some coralline crags from the uppermost Pliocene, there is a *40 Ma gap* in the sedimentary sequence.
- Geotechnical studies on the London Clay demonstrate that it is over-consolidated.
- As much as 600 m overburden may have been removed but there is *no* geological evidence for these sediments anywhere and there may be experimental reasons for the discrepancy.

Warden Point, Isle of Sheppey

Neogene Activity

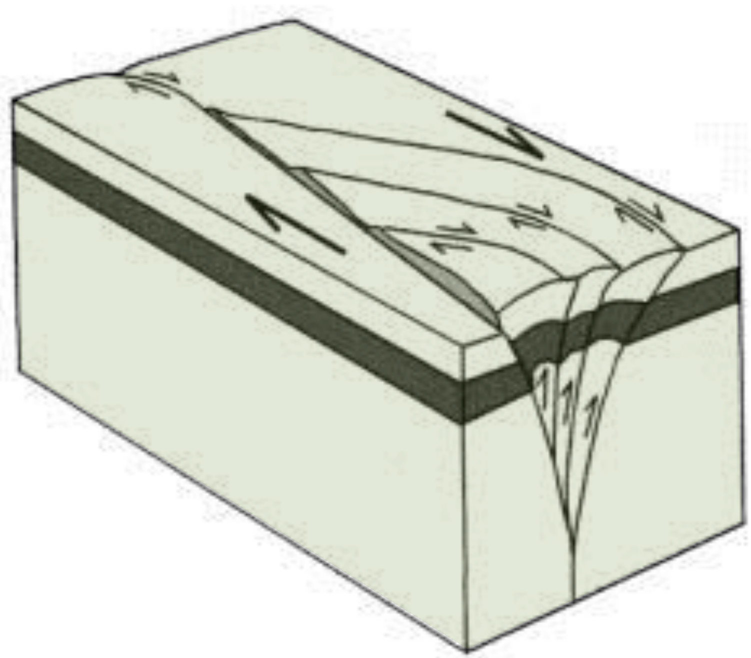
- We tend to think of the basin as subsiding, but the presence of coralline crag at the top of the North Downs is evidence for about *200 m of uplift* of the Weald in the last 3 Ma or so.
- River terraces indicate *average uplift rates of ~0·1 mm a^{-1}* across southern England and northern Europe in the same period.
- What are the causes of these movements?

Warden Point, Isle of Sheppey

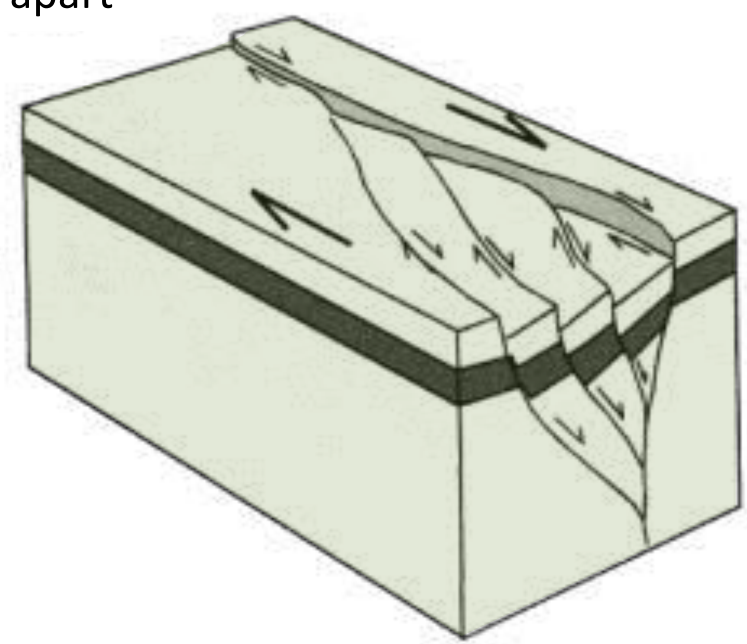
Strike-slip faults & near-surface deformation

- Pull-apart and push-up ‘flower’ structures at various scales
- Highly fractured to considerable depth and easily eroded
- Potential sites for scouring and later deposition and burial
- Detecting fault-controlled surface motion is one starting point

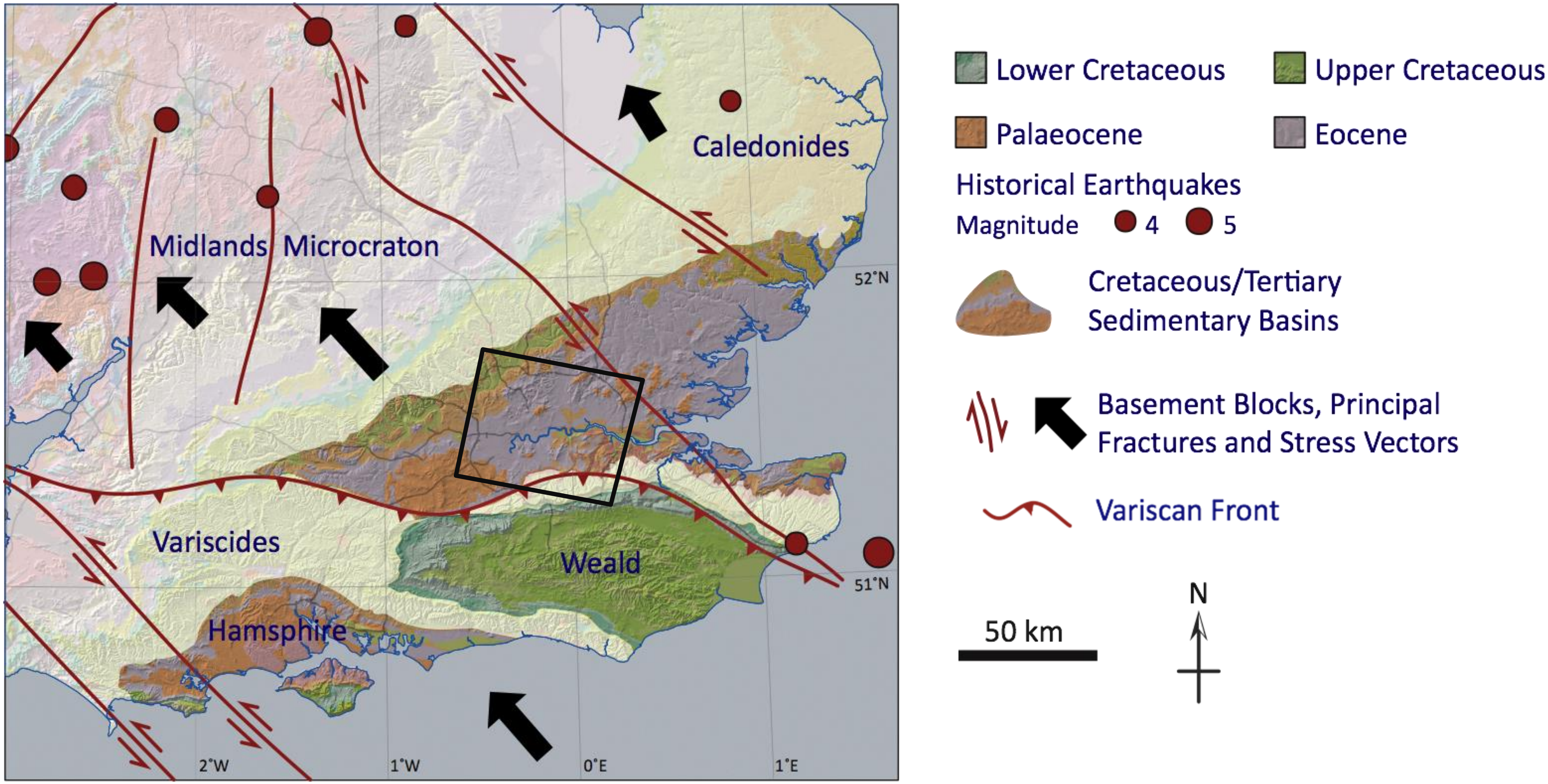
Push-up



Pull-apart



Variscan transtensional basins & basement fractures



The Cretaceous/Miocene transtensional basins and Variscan basement fractures of southern England. Black rectangle indicates approximate coverage of the London PSI dataset.

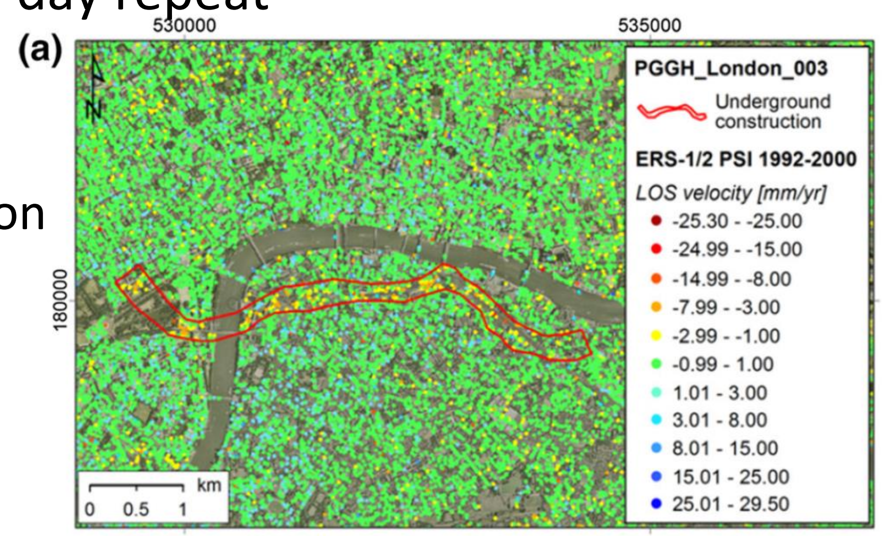
(Developed from Musson 2007, with Geological Map Data BGS © NERC 2013 and Ordnance Survey Data © Crown copyright/database right 2012. An Ordnance Survey/EDINA supplied service)

Detecting Ground Movements – What we have done so far

- Interested in finding evidence of ground movement /deformation
- Obtained a Persistant Scatterer InSAR (PSI) dataset of London
  - Kindly provided by CGG (NPA Satellite Mapping)
  - Spanning ~ 20 year period (1992 – 2010)
- Analysis of regional and local PSI patterns
- Comparison with known structural framework
- Gathering other and complimentary data

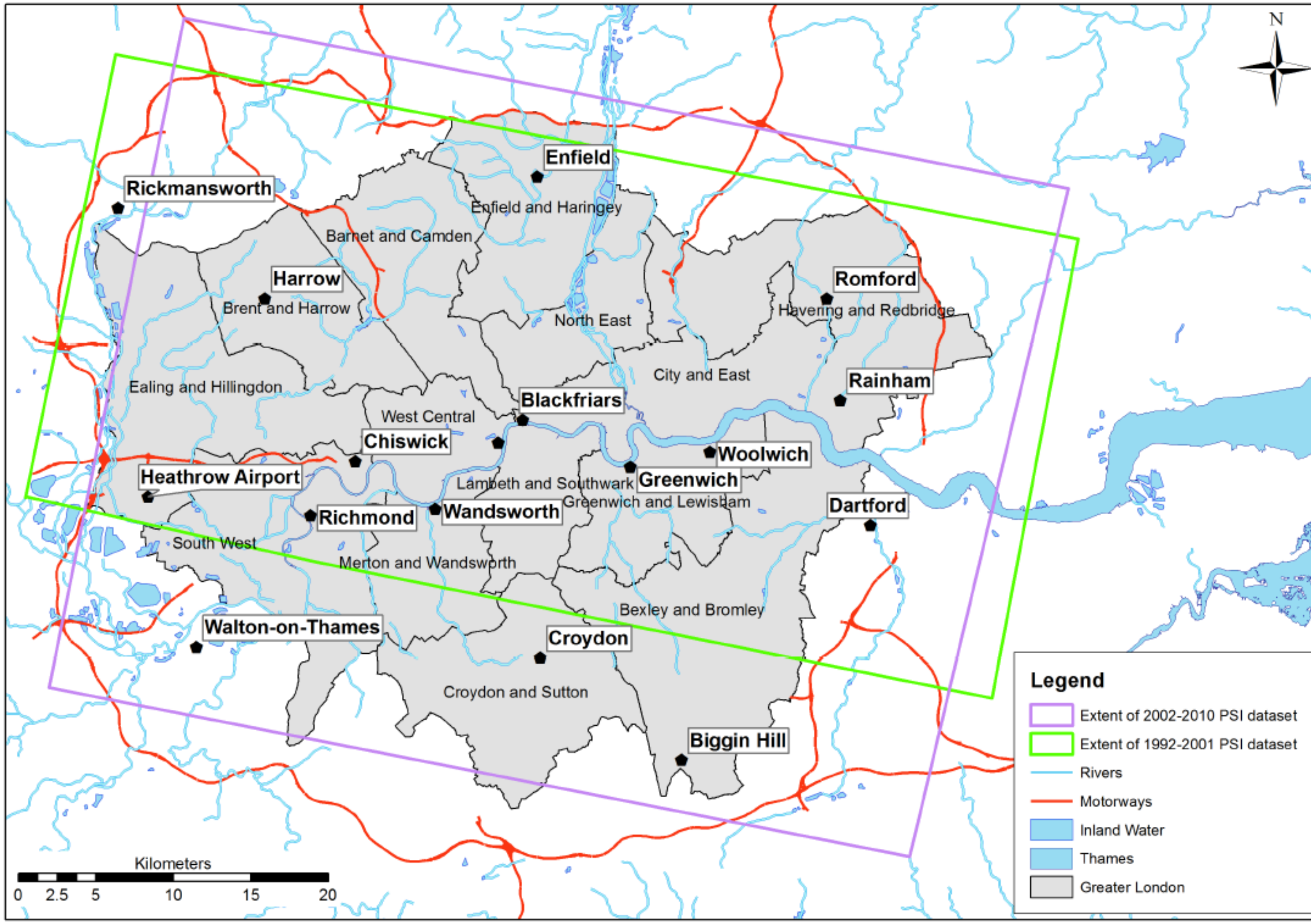
Persistent Scatterer InSAR (PSI)

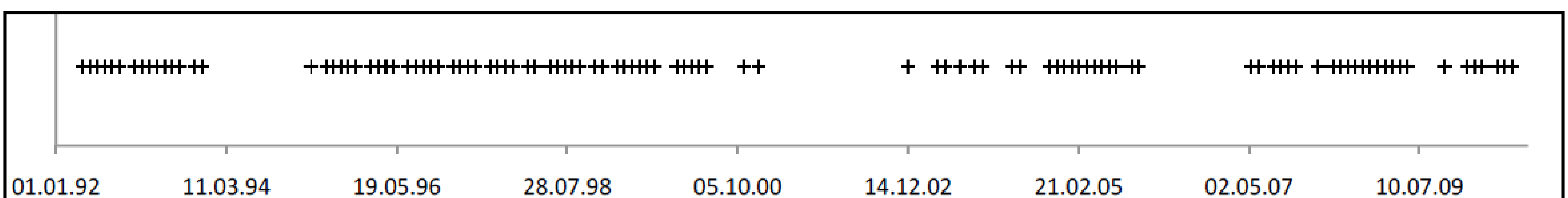
- Advanced development of differential interferometric SAR
- Identifying and exploiting individual radar reflectors, or ‘persistent scatterers’, at sub-pixel level, which remain coherent over long time intervals; to develop a displacement time series
- Large numbers of multi-temporal SAR data scenes
- PS ground objects used to detect and measure millimetric displacements between scenes
- Commonly 1000s persistent scatterers per sq km
- 20 years of archive (ERS & Envisat) available
- Sentinel-1 SAR – ongoing coverage 12 day repeat
- Widely used to
  - Identify temporal and spatial change
  - Monitor vert. and horiz. ground motion
  - Measure rates of mm to cm p a



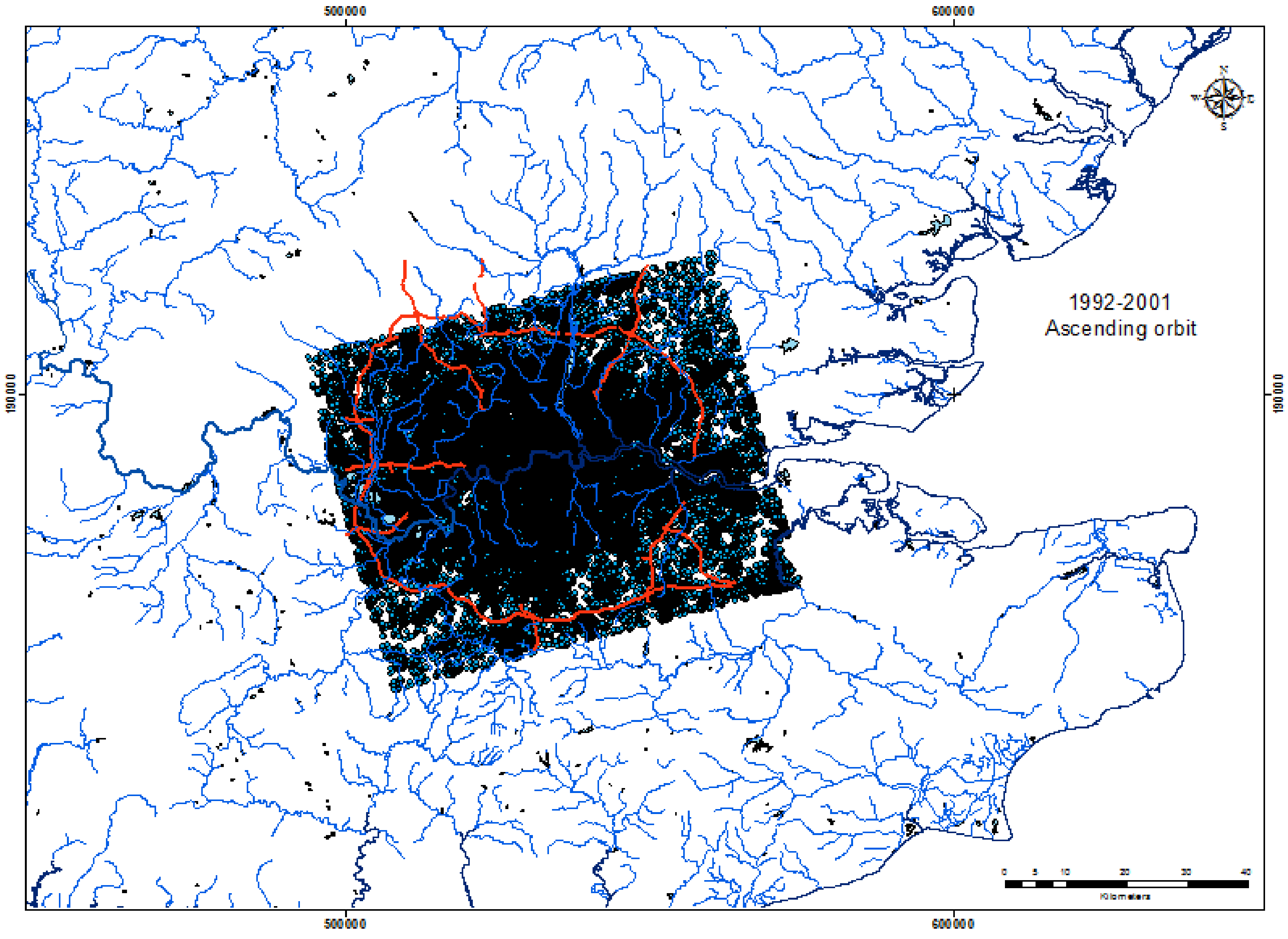
London PSI datasets

Generated from an ERS & Envisat data archive spanning a 20 year period

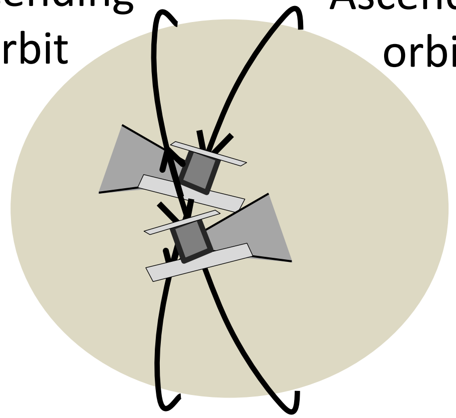




London PSI datasets

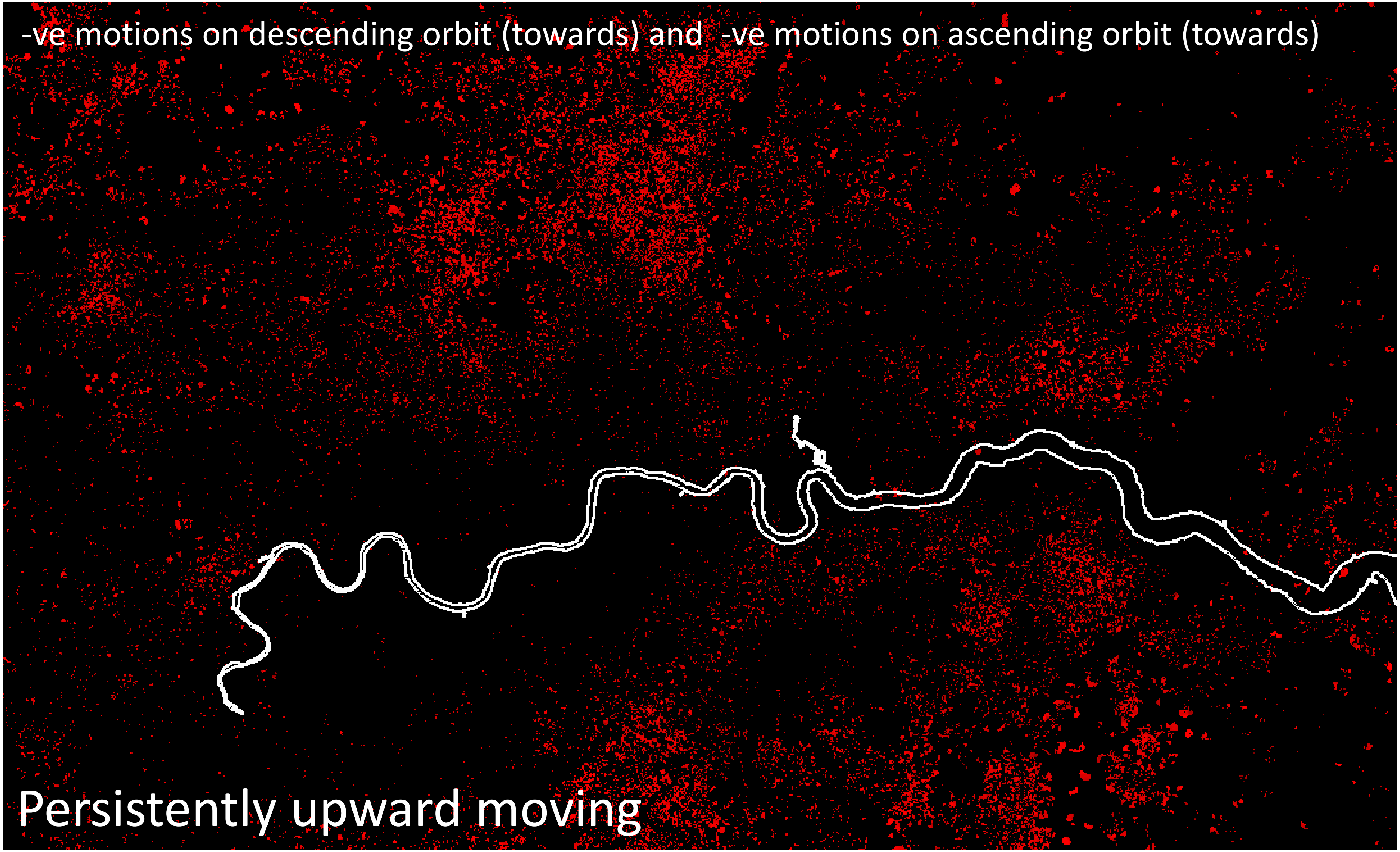


London PSI dataset generation

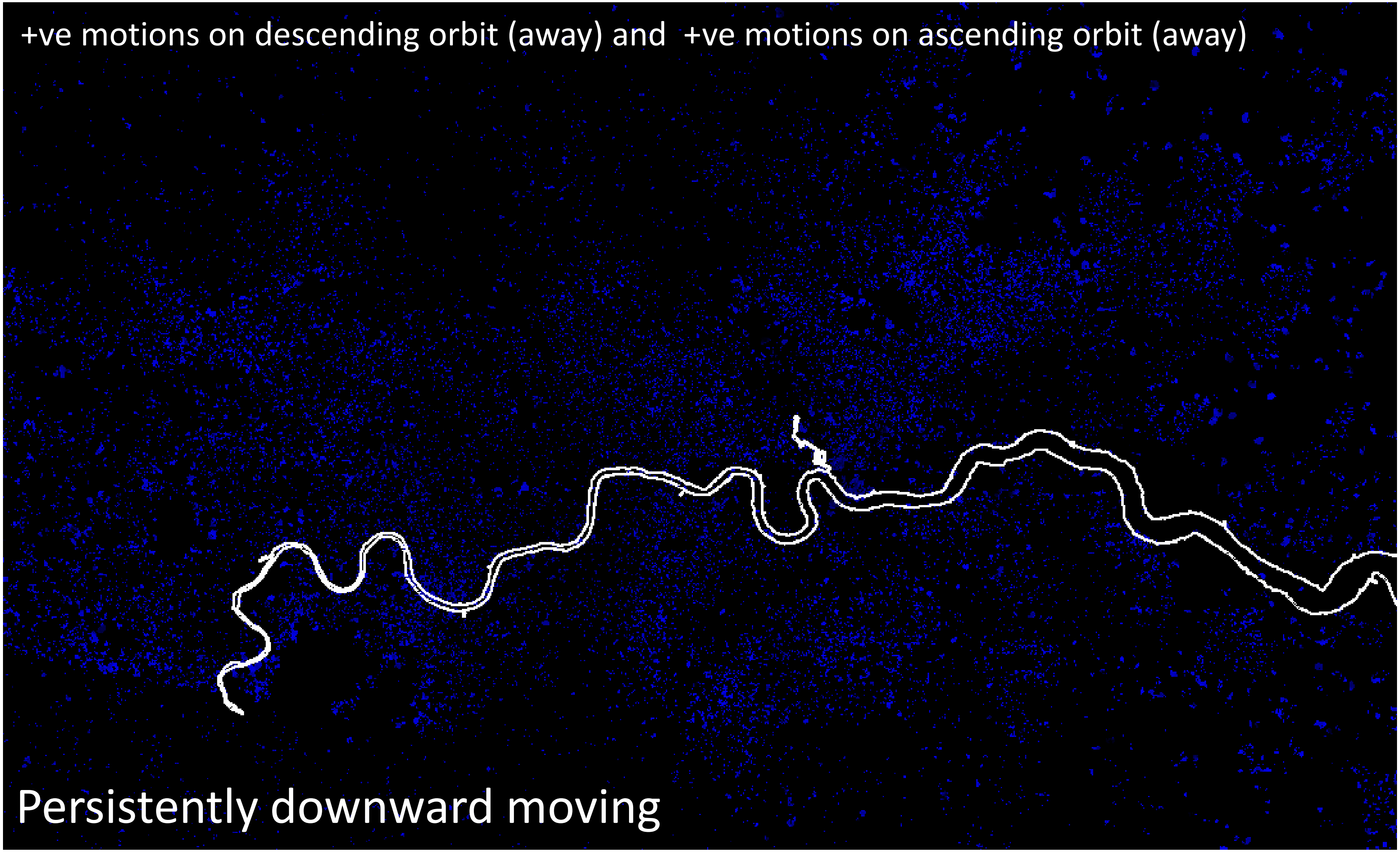


- Pre-Sentinel-1 data only (ERS & Envisat) thus far
- Ascending & descending orbital geometry
  - Partial coverage from ascending orbit – no Envisat
- Line of sight measurements (mm) of ground velocity
  - Away from sensor – positive
  - Toward sensor – negative
  - PSI provides measure of vertical and lateral (eastward or westward) movements (E on the ascending orbit and W on the descending orbit as a function of its 'right-looking' aperture)
- Predicted accuracies
  - Detect a displacement rate of <1 mm a^{-1}
  - Individual displacements of ~5 mm
- Irregular point data distribution
  - Production of gridded surfaces to enable comparison
  - After gridding, we ignore very high magnitude movements – assumed to be caused by construction

PSI Vertical Movements



PSI Vertical Movements



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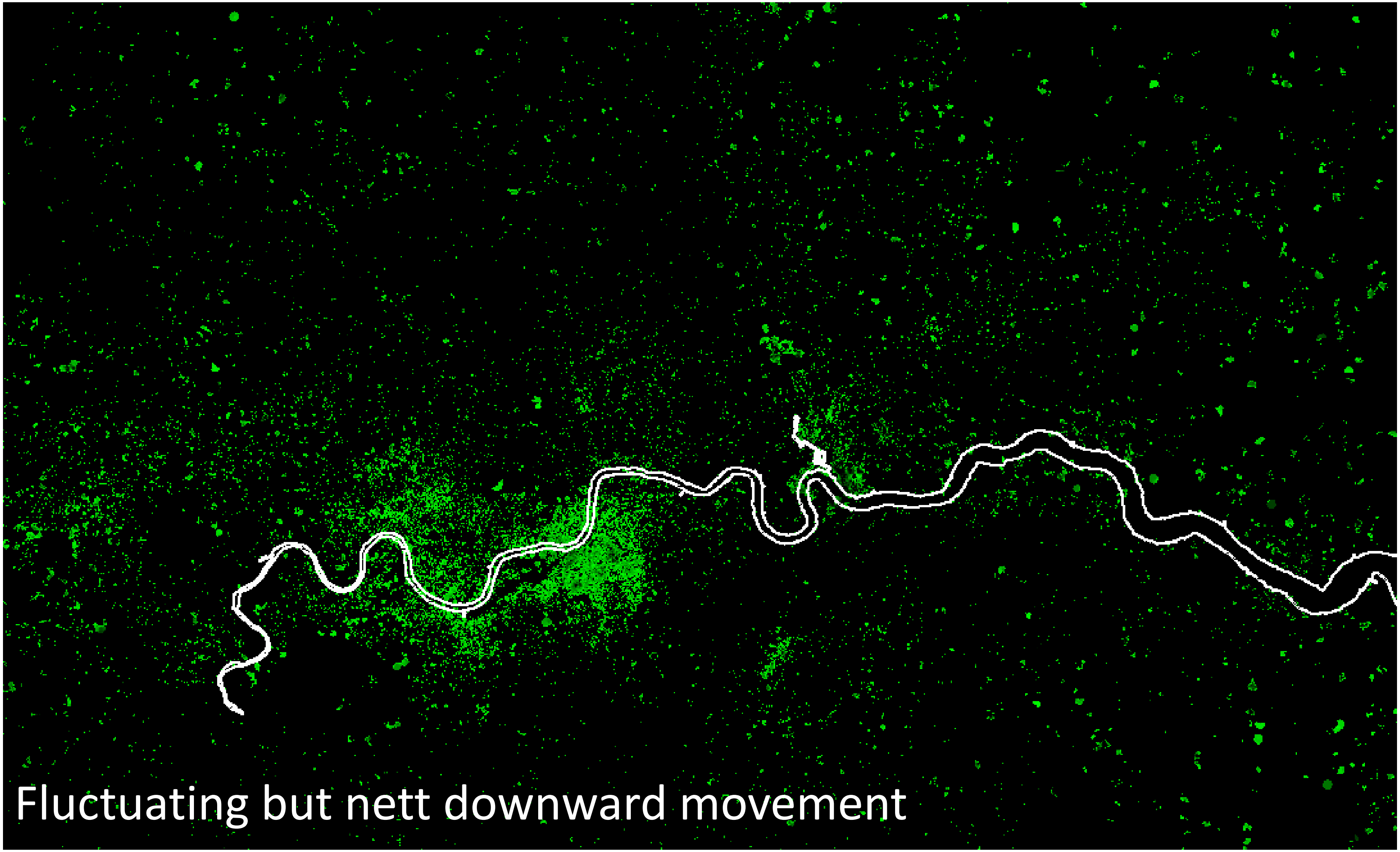

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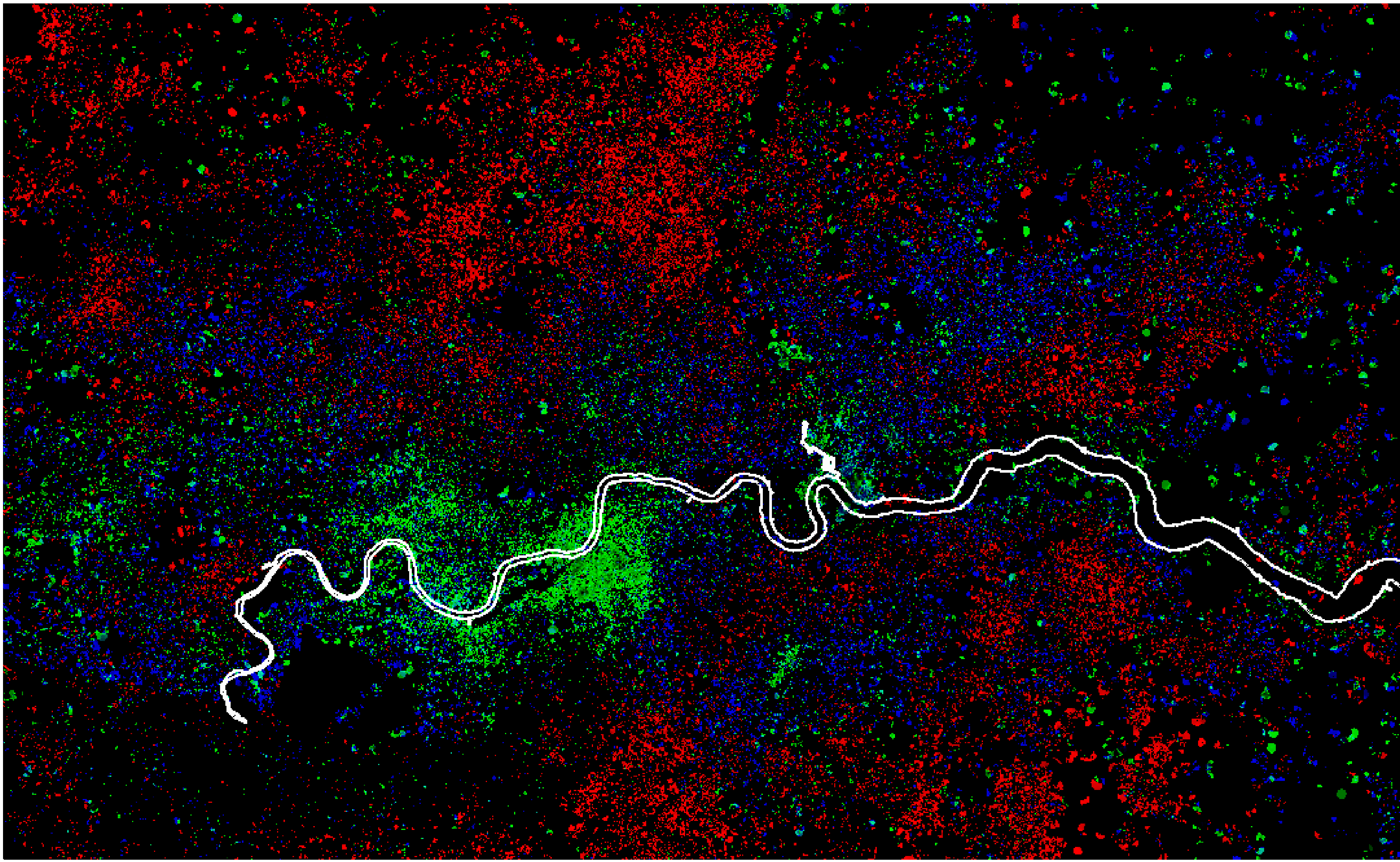
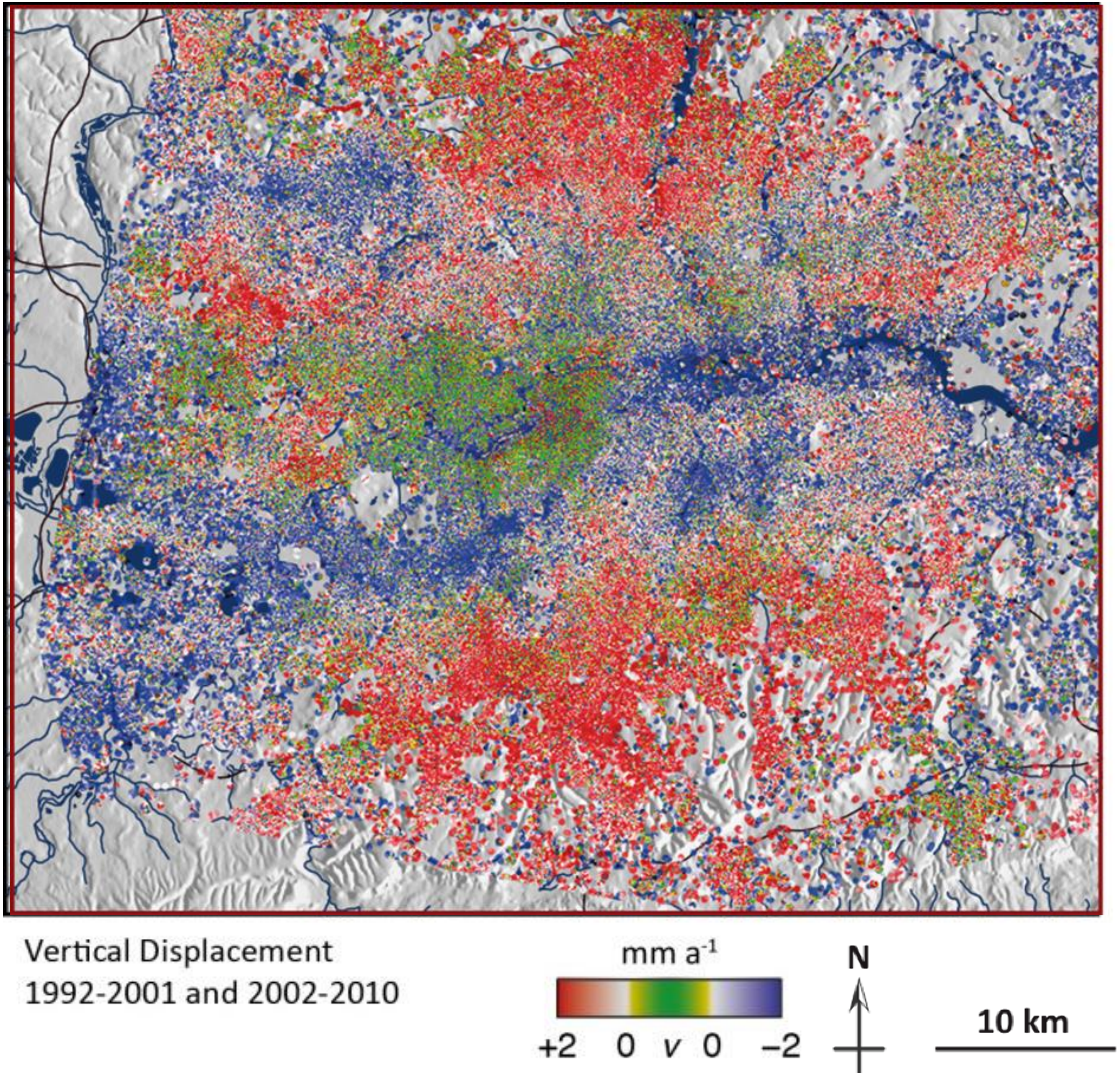


PSI Vertical Movements

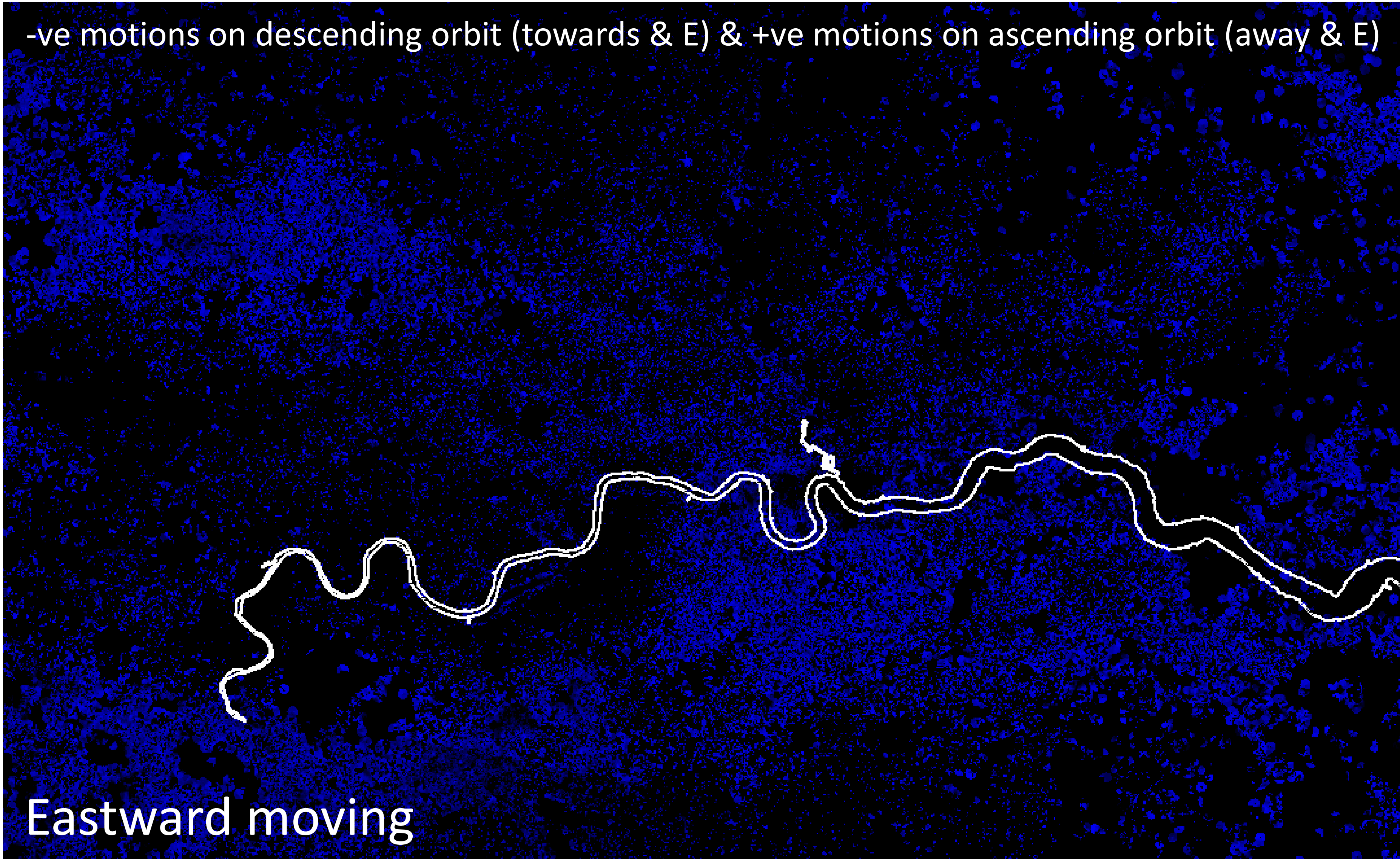
ERS data from ascending and descending orbits

Vertical displacements over two decades reveal:

- Consistent pattern of subsidence in the Thames valley
- Uplift in the north, south and west.
- Fluctuating in west central London indicating uplift in one time period and subsidence in the other.



PSI Lateral Movements



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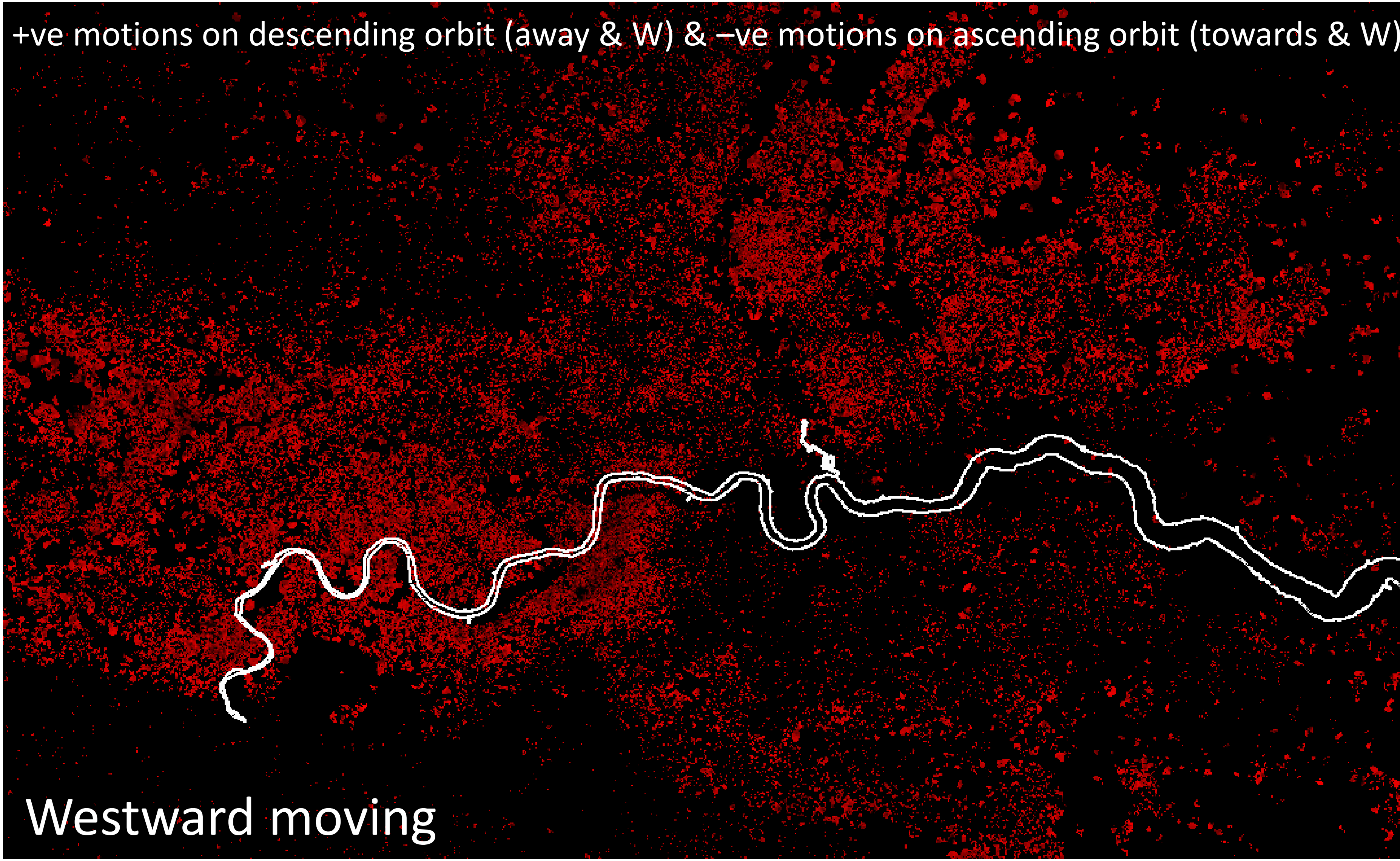

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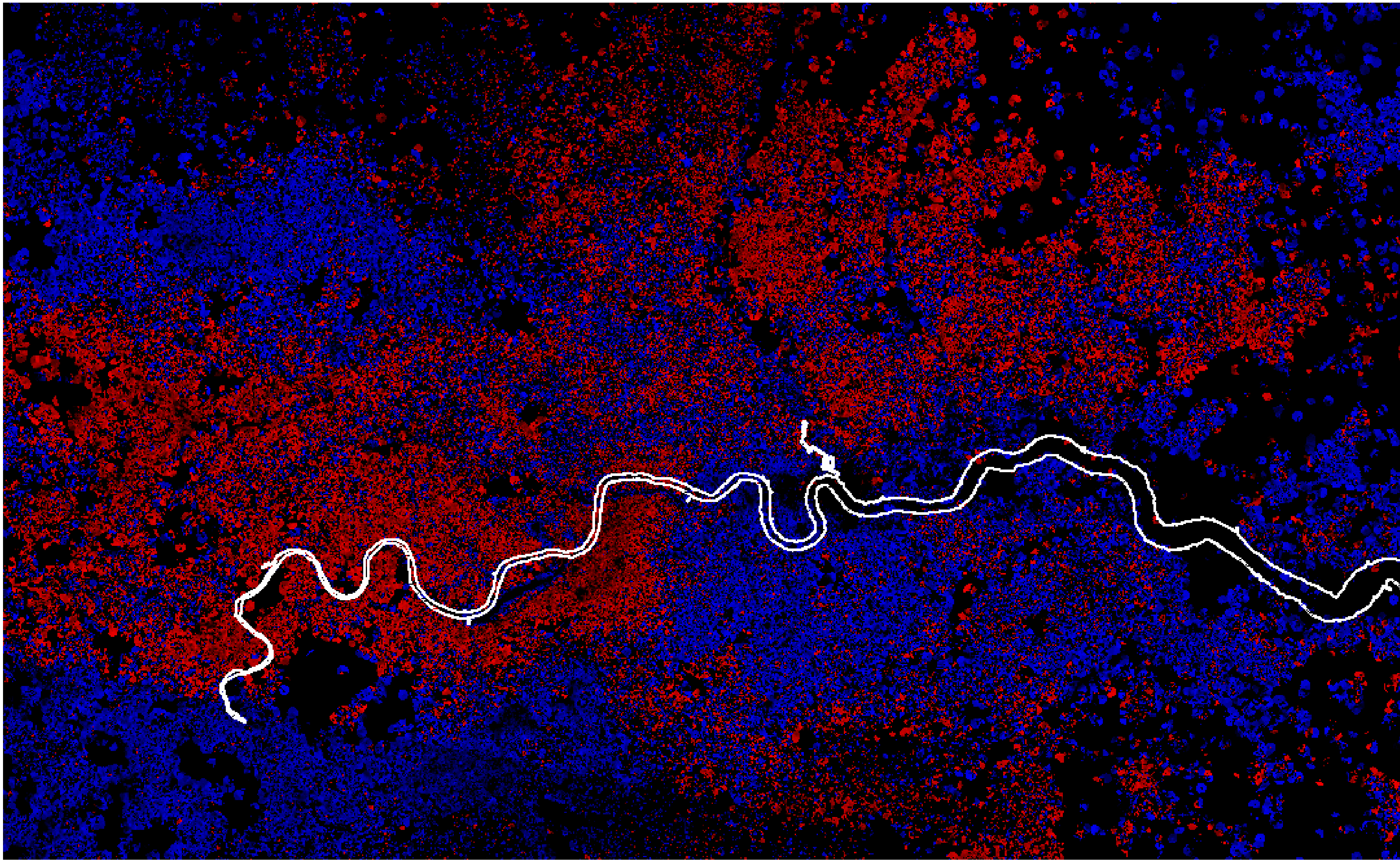
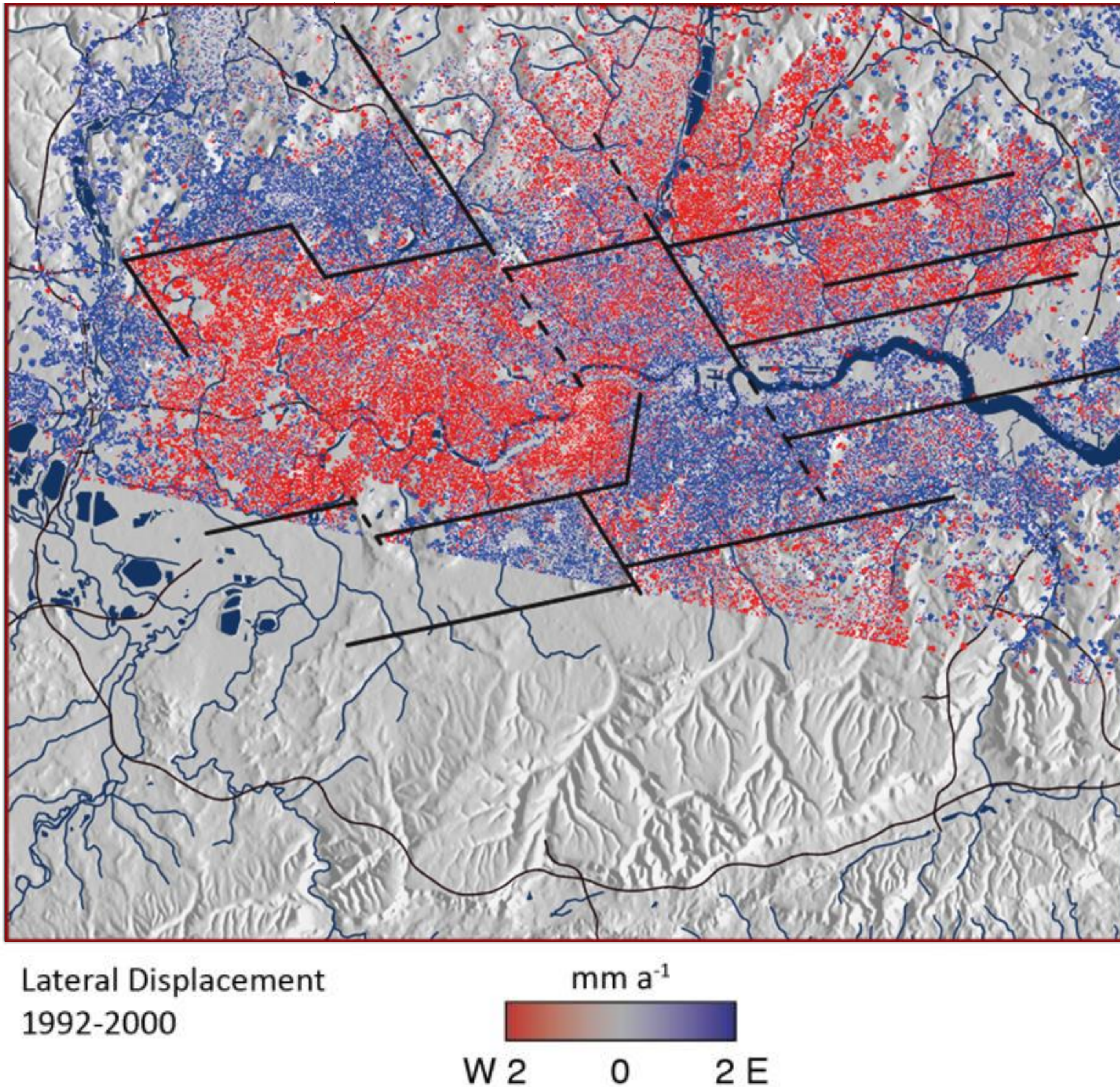


PSI Lateral Movements

ERS data from ascending and descending orbits

Lateral component of displacement reveals:

- Two large west-moving blocks in the west and NE
- Two east-moving blocks in the NW and SE
- Patterns in the centre and far SE are less clear



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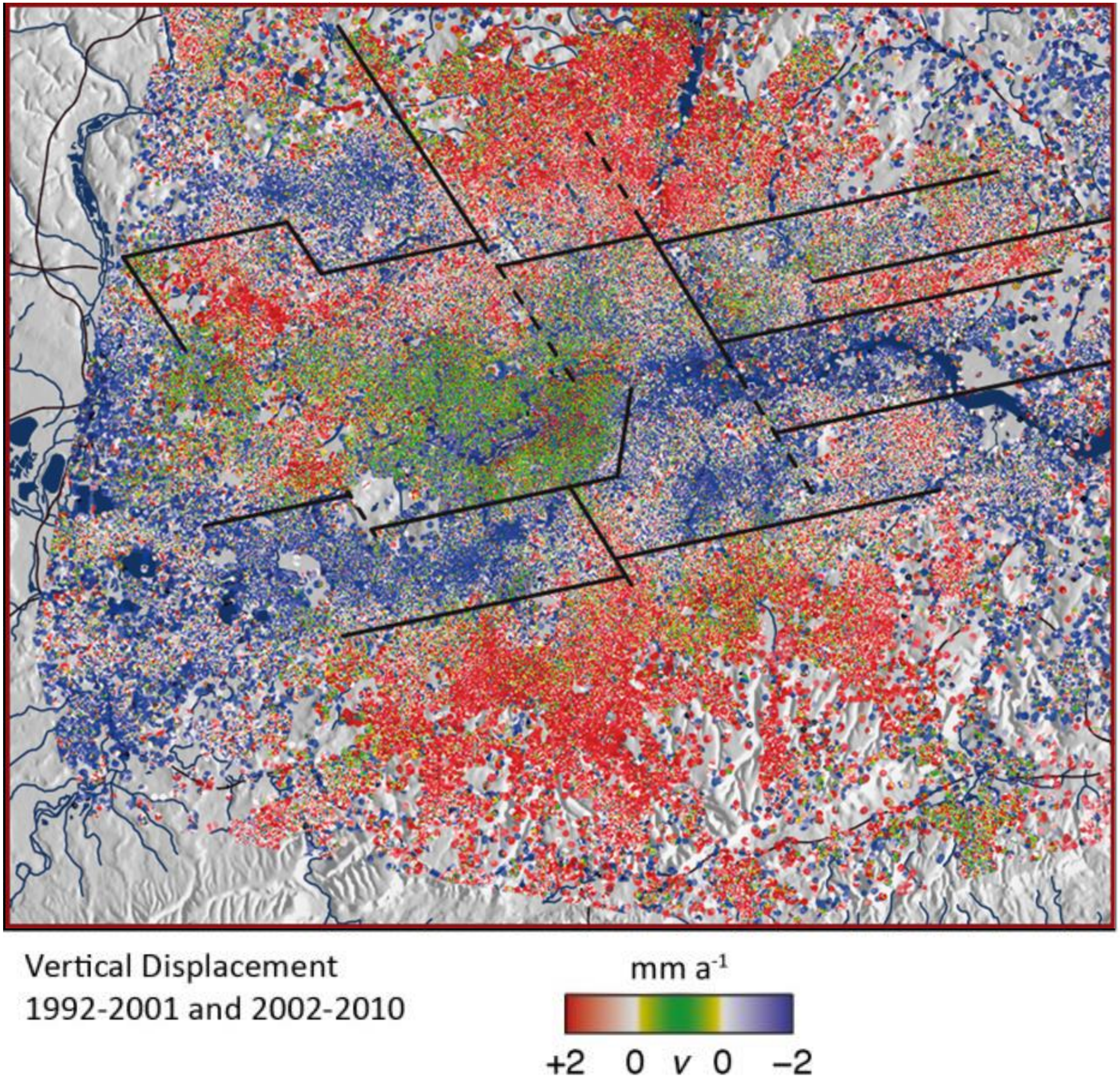


Interpretation….what does it all mean?

Mean rates of ground displacement across London identified from PSI data analysis

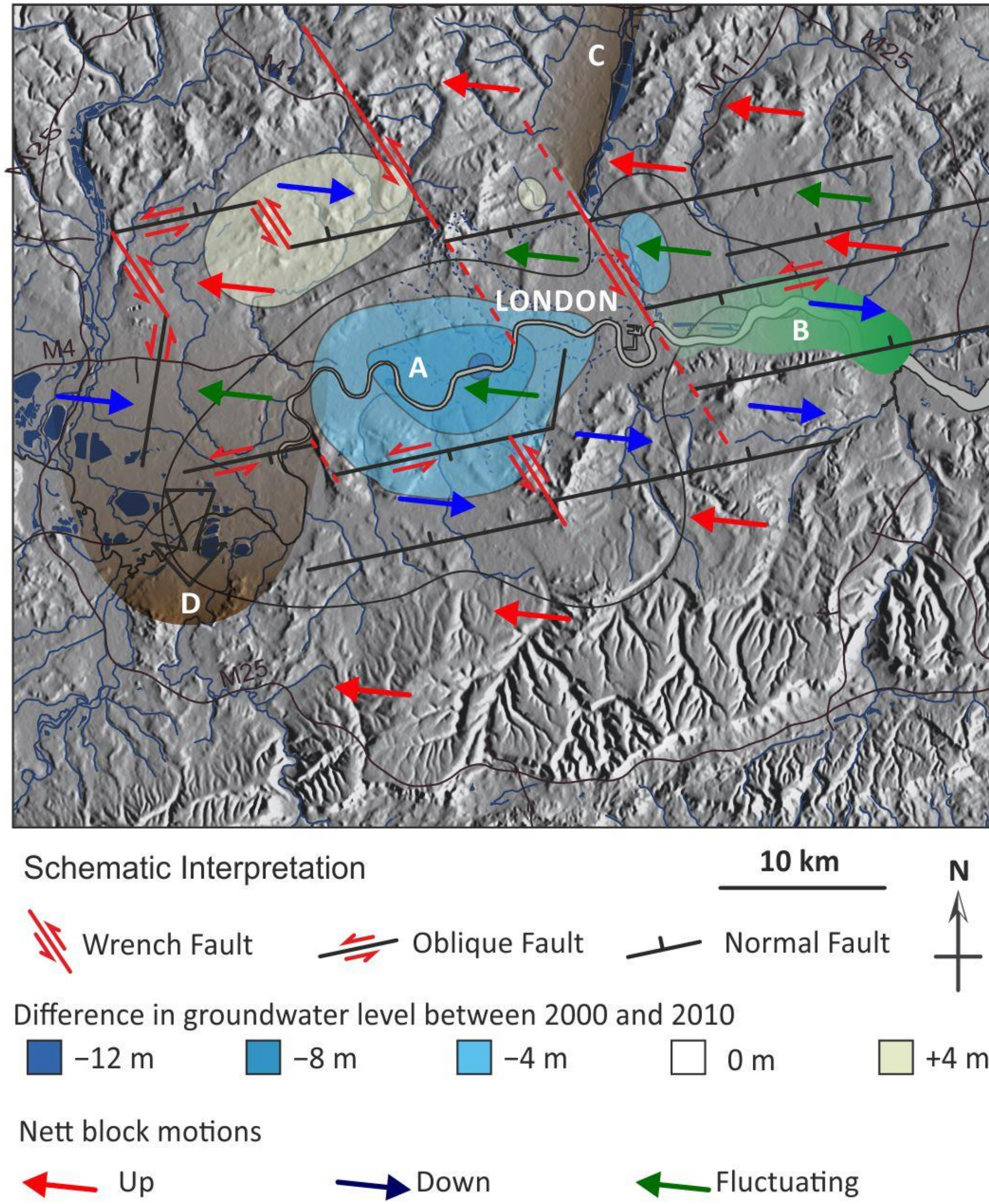
Region	Vertical	Lateral
North east	+0·17 ± 0·46 mm a^{-1}	1·06 ± 1·60 mm a^{-1} W
Estuary	−0·61 ± 0·74 mm a^{-1}	1·09 ± 1·48 mm a^{-1} E
South east	+0·09 ± 0·53 mm a^{-1}	1·01 ± 1.49 mm a^{-1} W
West	+0·28 ± 0·52 mm a^{-1}	0·99 ± 1·41 mm a^{-1} W

GPS mean rate: **0.7 ± 1.6 mm a^{-1} to 323N ± 15˚** (after correction for the absolute plate motion vector of 24 mm a^{-1} to 051N)

Geological change in the London region.

a) River terrace and loess deposits of the last 420 k a nearly all lie to the north of the modern Thames and to the NW of the upper Lea.

b) Interpretive cartoon of the major features observed and the potentially faulted boundaries between them



To conclude

- London and SE England are moving, by ca 1 mm p a^{-1}
- Movements detectable using InSAR technologies (PSI and DInSAR)
- Movements fault controlled

Ongoing work

- Refinement of the technique
- High temporal frequency of Sentinel-1 data means DInSAR rather than PSI can also be used
- Metropolitan sites in tectonically quiescent (intraplate) regions – London, Berlin, Reykjavík – in areas experiencing small scale movements on a range of scales (mm to cm)