Ongoing deformation of Antarctica following recent Great Earthquakes

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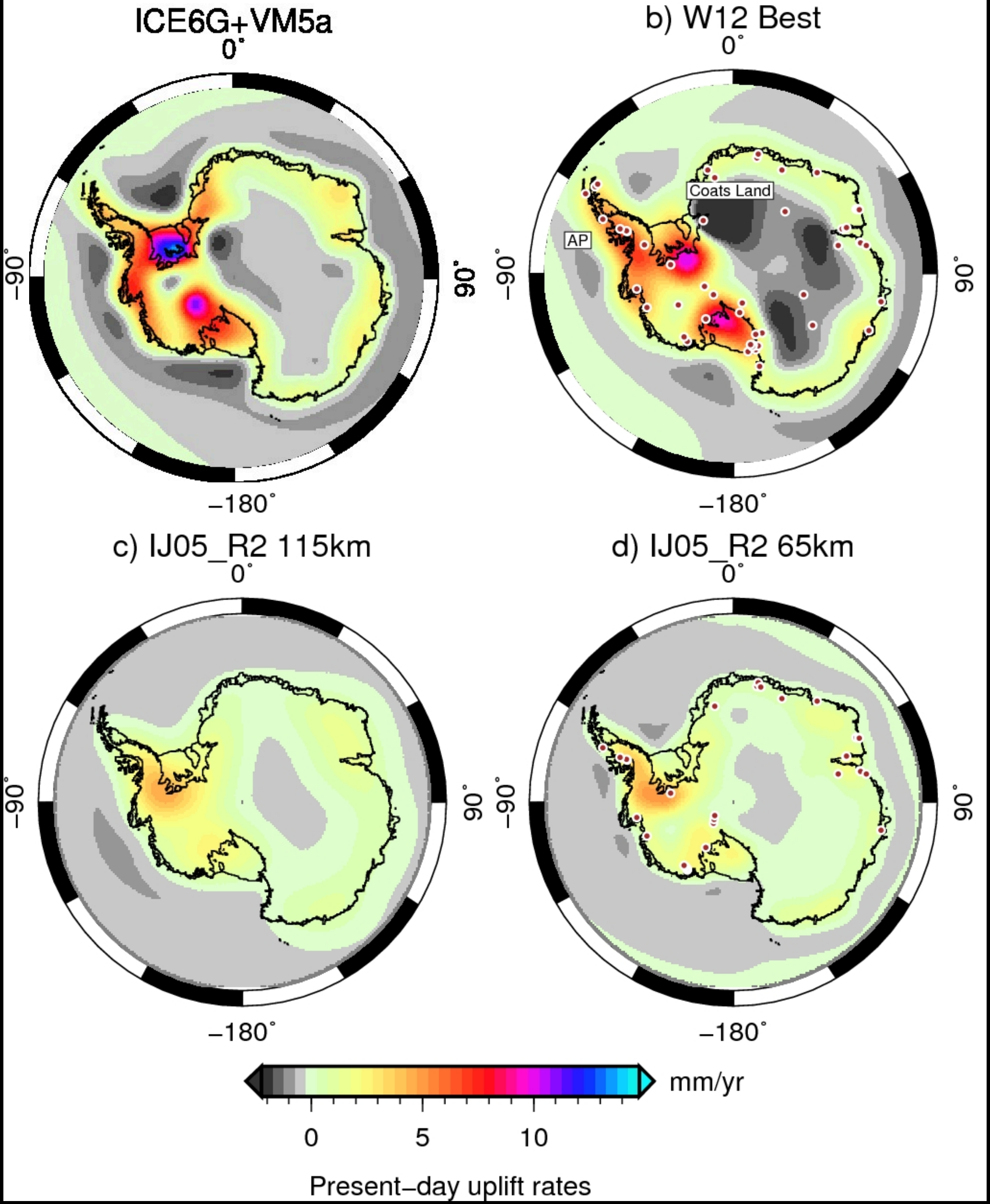
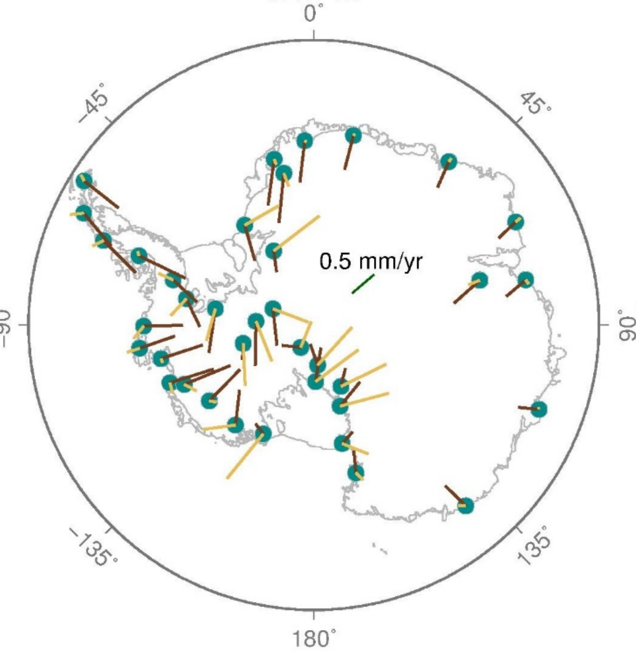
Australian Government
Australian Research Council
MARIE CURIE ACTIONS



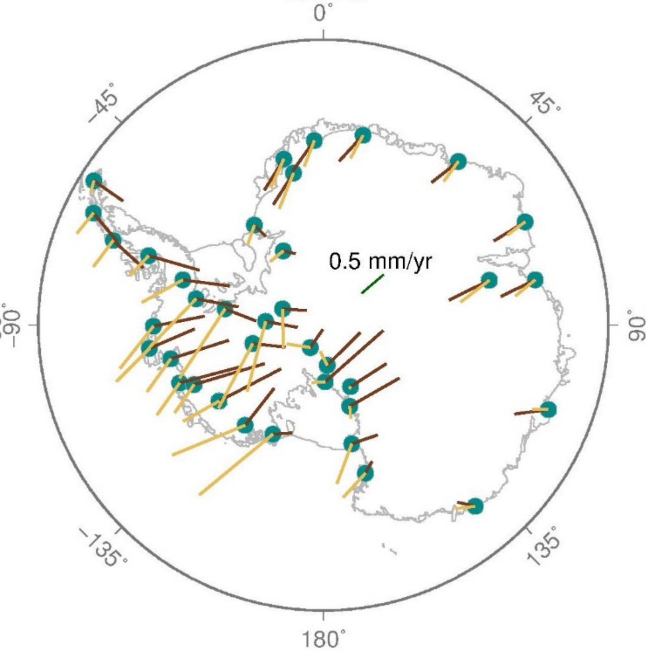
Modelled present-day bedrock uplift due to GIA

Modified from King (2013)

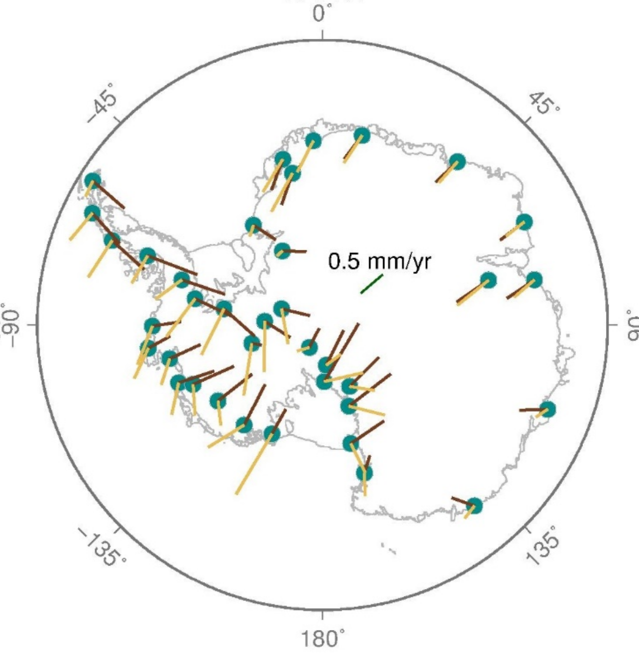
W12 1D



W12 G

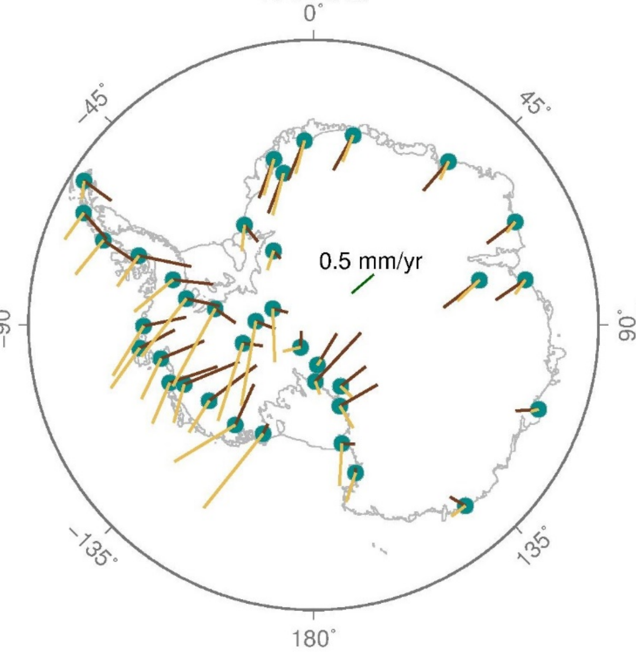


W12 K

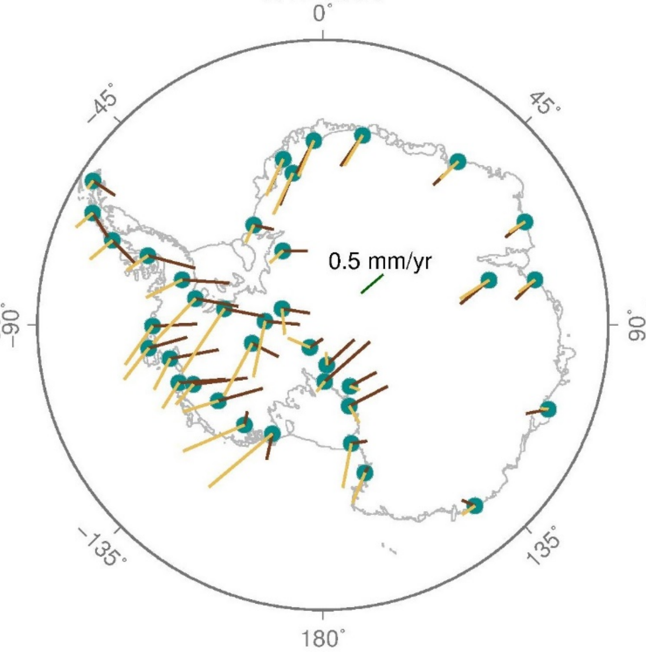


King et al. 2015

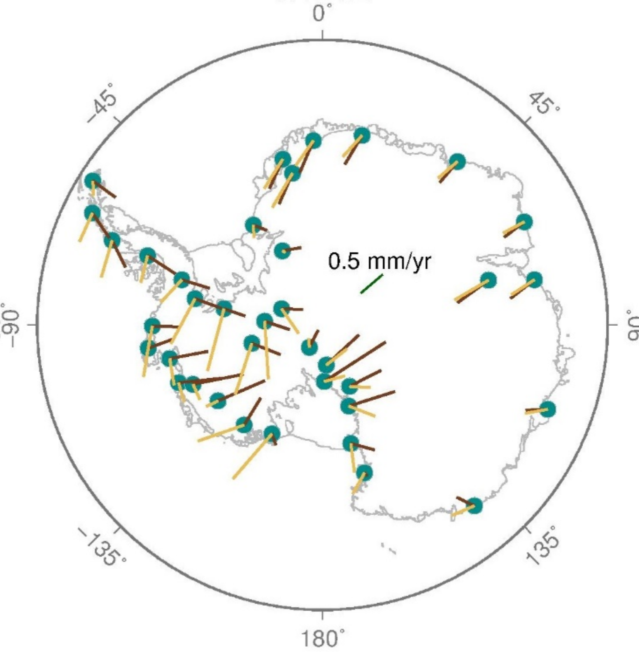
W12 S40



W12 SAW



W12 SL

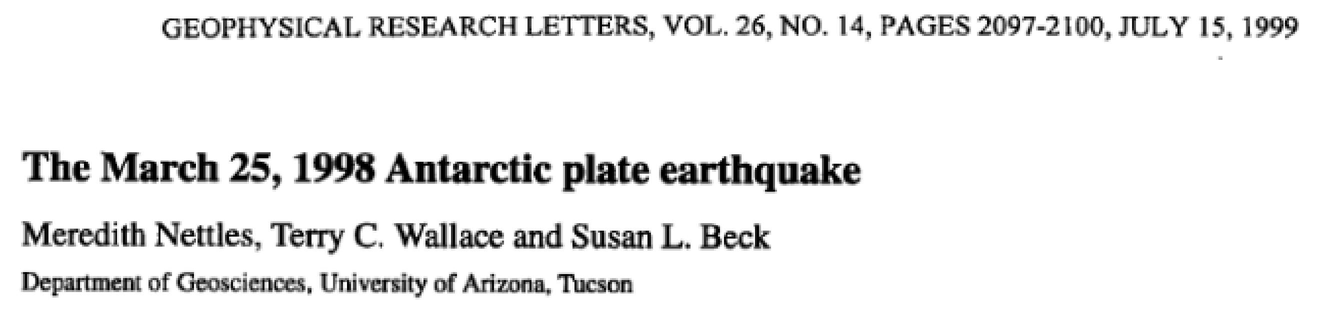


Motion of Antarctica

- Generally assumed to be dominated by
  - internal deformation due to GIA – horizontal and vertical
  - plate rotation – horizontal

Motion of Antarctica

- Generally assumed to be dominated by
  - internal deformation due to GIA – horizontal and vertical
  - plate rotation – horizontal
- Is that always true?



GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO. 14, PAGES 2097-2100, JULY 15, 1999

The March 25, 1998 Antarctic plate earthquake

Meredith Nettles, Terry C. Wallace and Susan L. Beck
Department of Geosciences, University of Arizona, Tucson

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 105, NO. B7, PAGES 16,097–16,118, JULY 10, 2000

The great March 25, 1998, Antarctic Plate earthquake: Moment tensor and rupture history

C. Henry, S. Das, and J. H. Woodhouse
Department of Earth Sciences, University of Oxford, Oxford, England, United Kingdom

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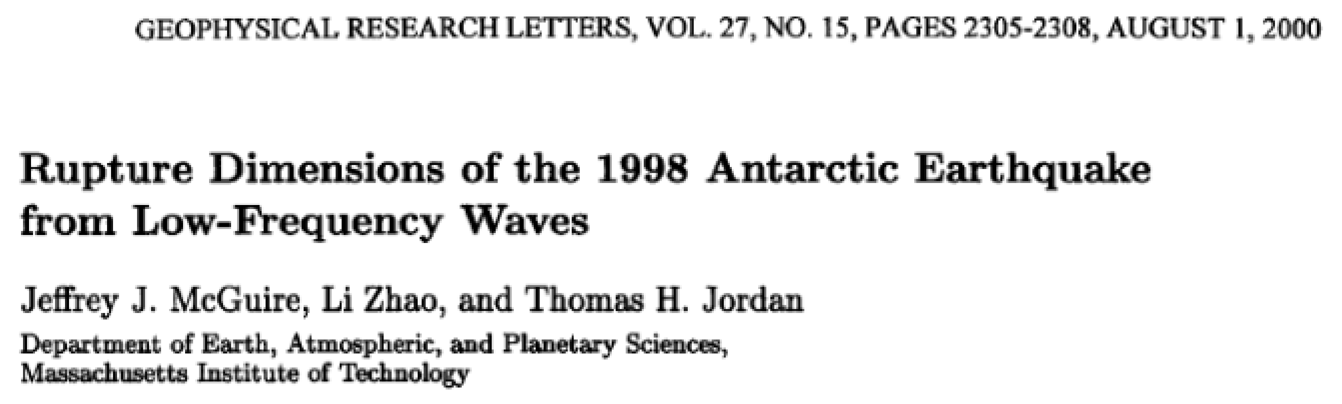
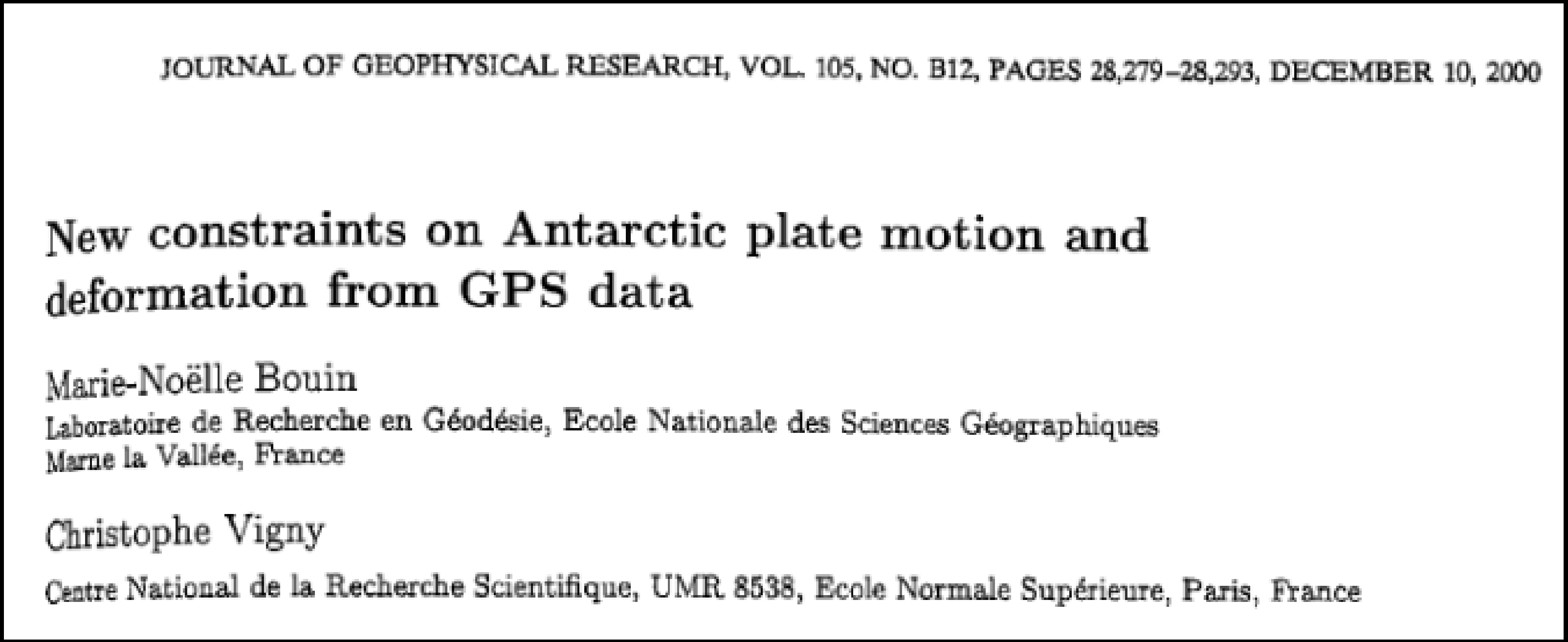


GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 15, PAGES 2305-2308, AUGUST 1, 2000

Rupture Dimensions of the 1998 Antarctic Earthquake from Low-Frequency Waves

Jeffrey J. McGuire, Li Zhao, and Thomas H. Jordan
Department of Earth, Atmospheric, and Planetary Sciences,
Massachusetts Institute of Technology

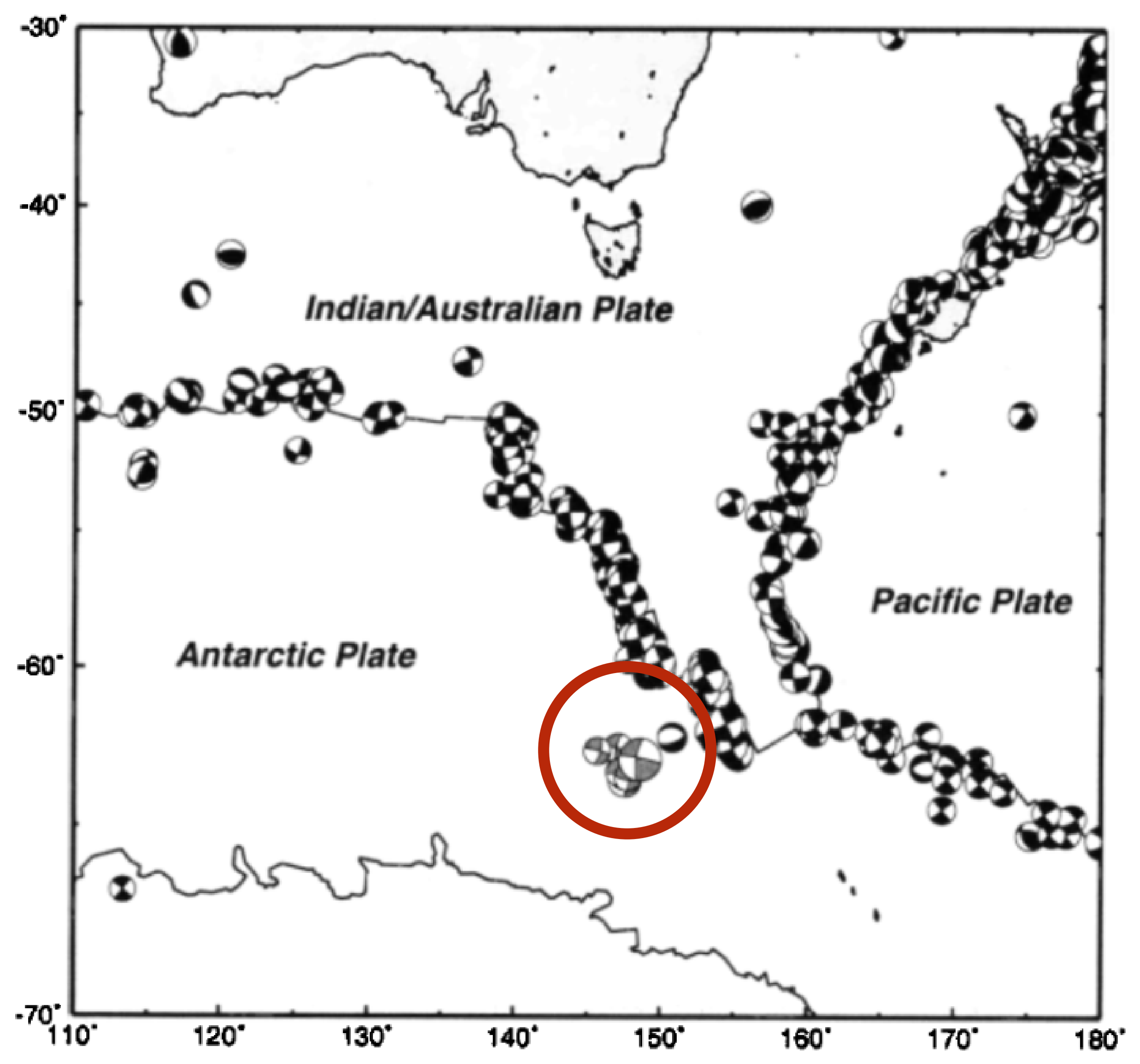


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 105, NO. B12, PAGES 28,279–28,293, DECEMBER 10, 2000

New constraints on Antarctic plate motion and deformation from GPS data

Marie-Noëlle Bouin
Laboratoire de Recherche en Géodésie, Ecole Nationale des Sciences Géographiques
Marne la Vallée, France

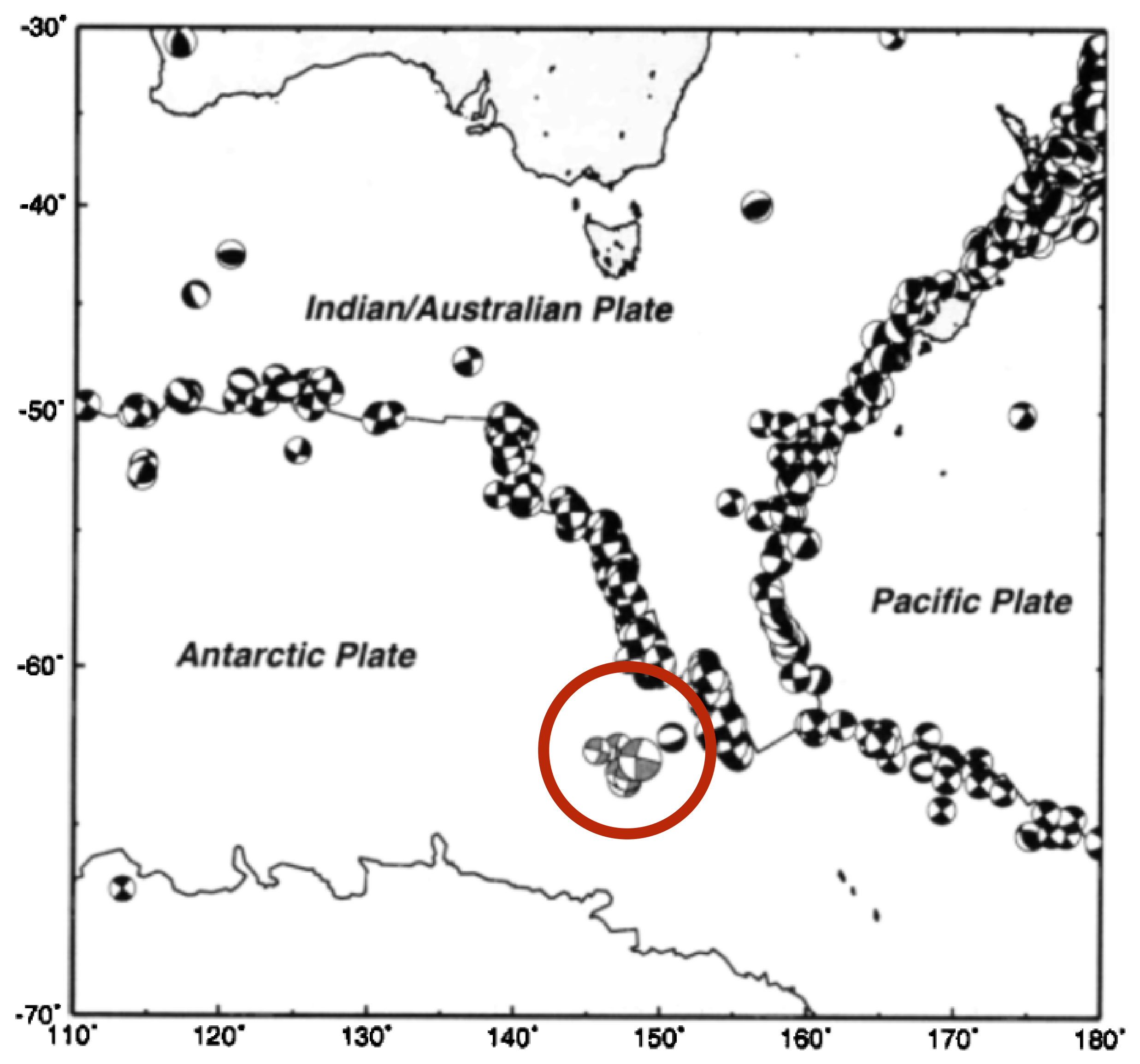
Christophe Vigny
Centre National de la Recherche Scientifique, UMR 8538, Ecole Normale Supérieure, Paris, France



Nettles et al 1999

300km south of plate boundary

500km north of Antarctica



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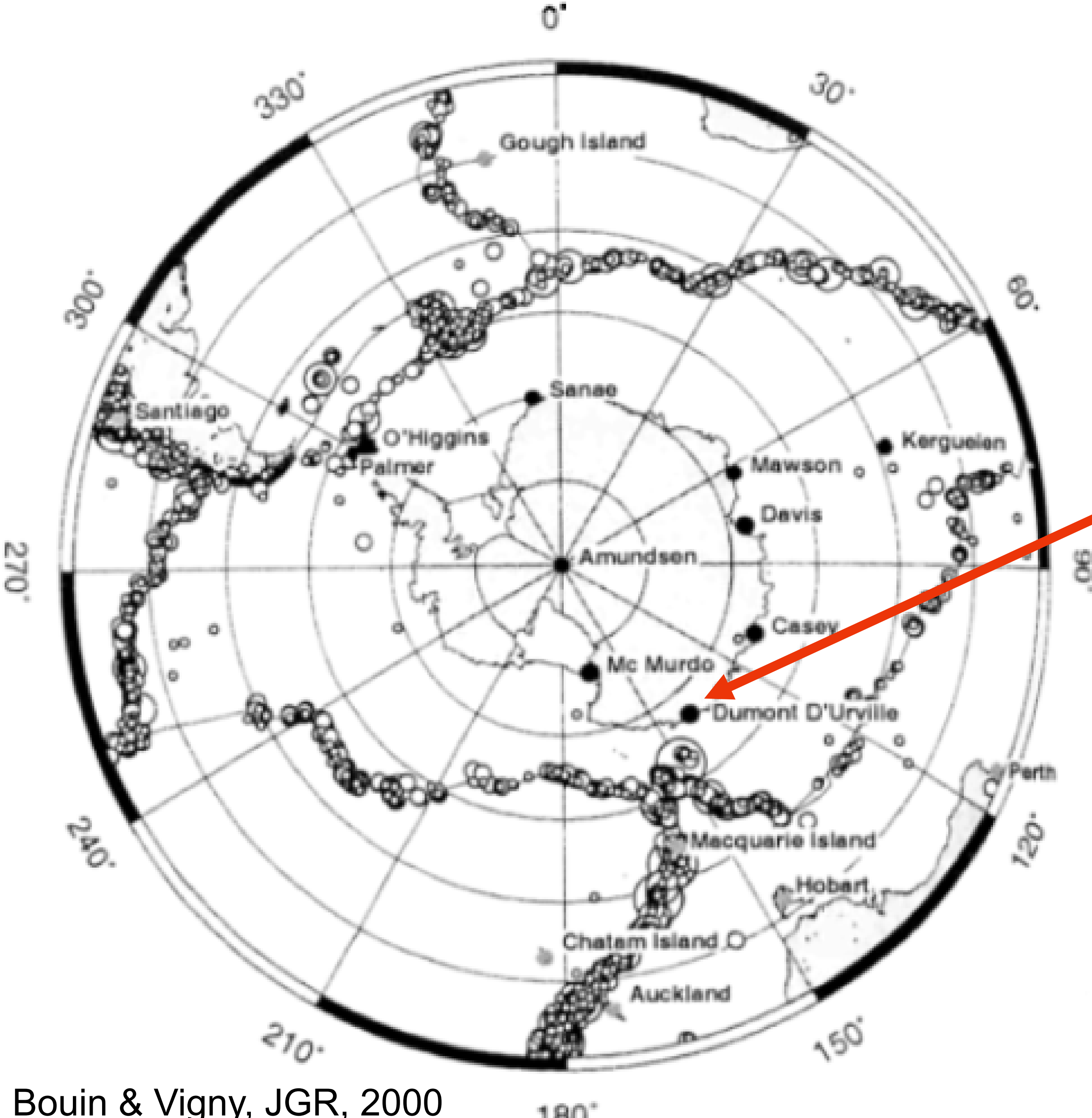
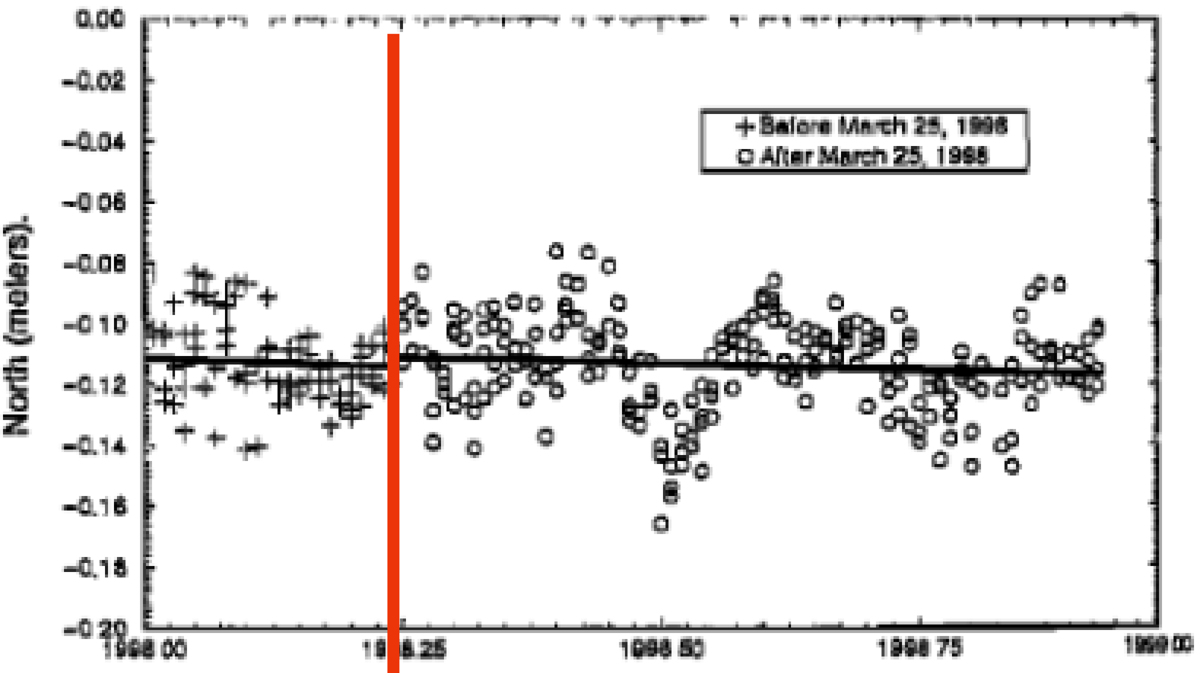


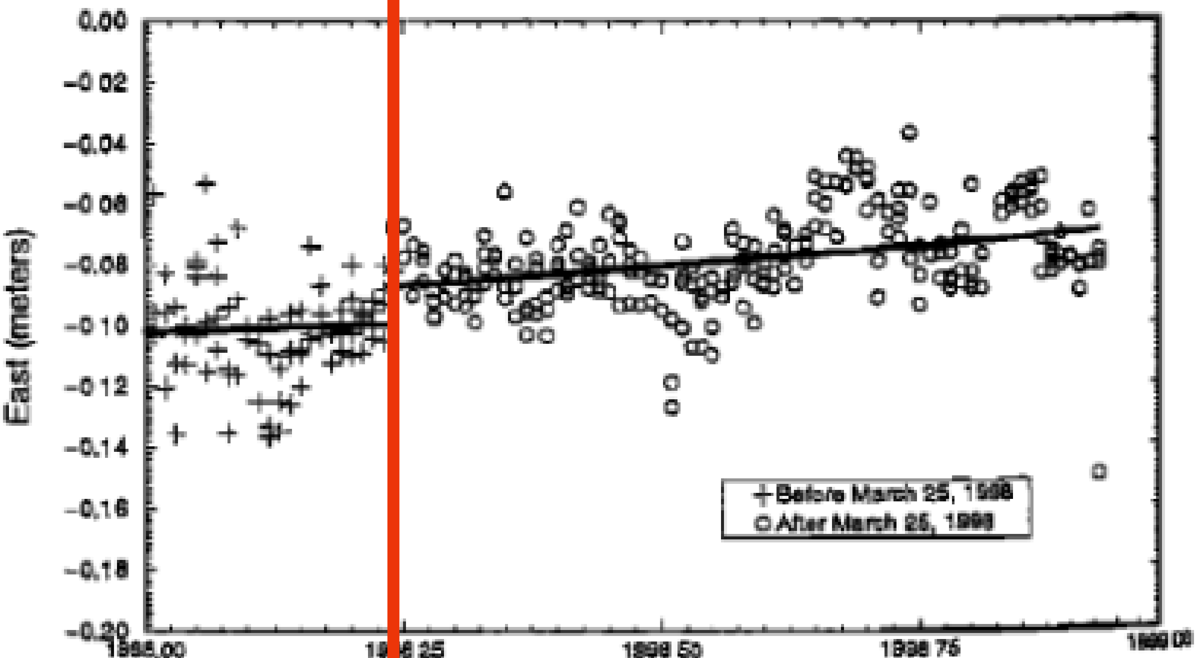
DORIS and GPS

Bouin & Vigny, JGR, 2000

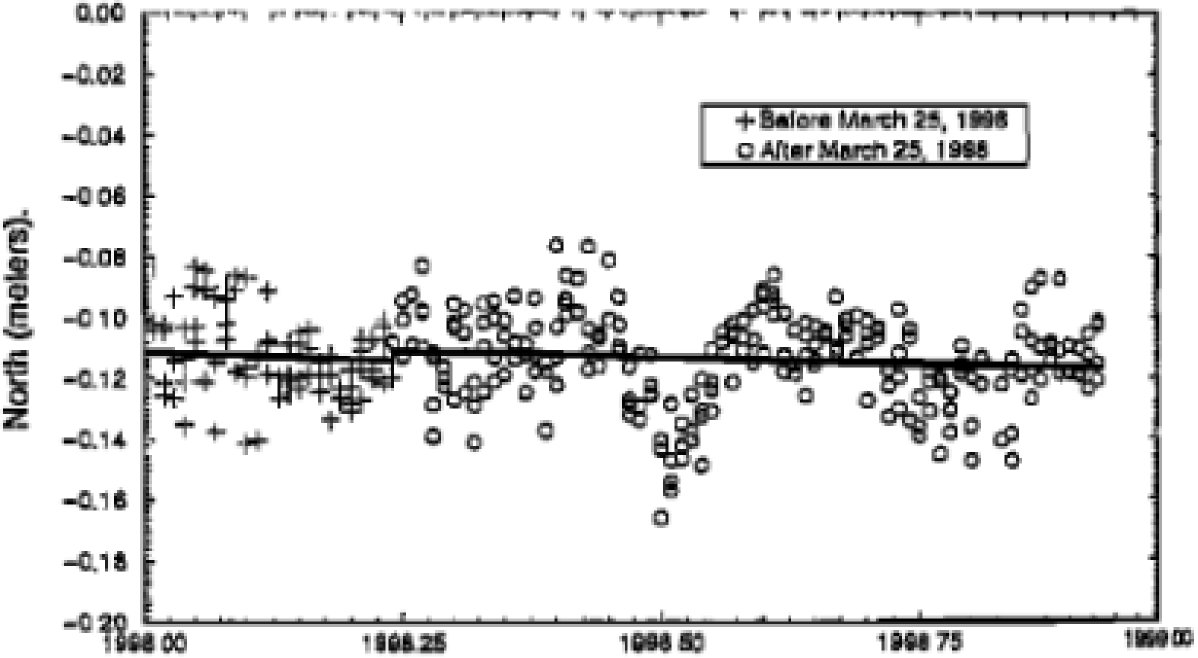


4±? mm
estimated

Bouin & Vigny, JGR 2000

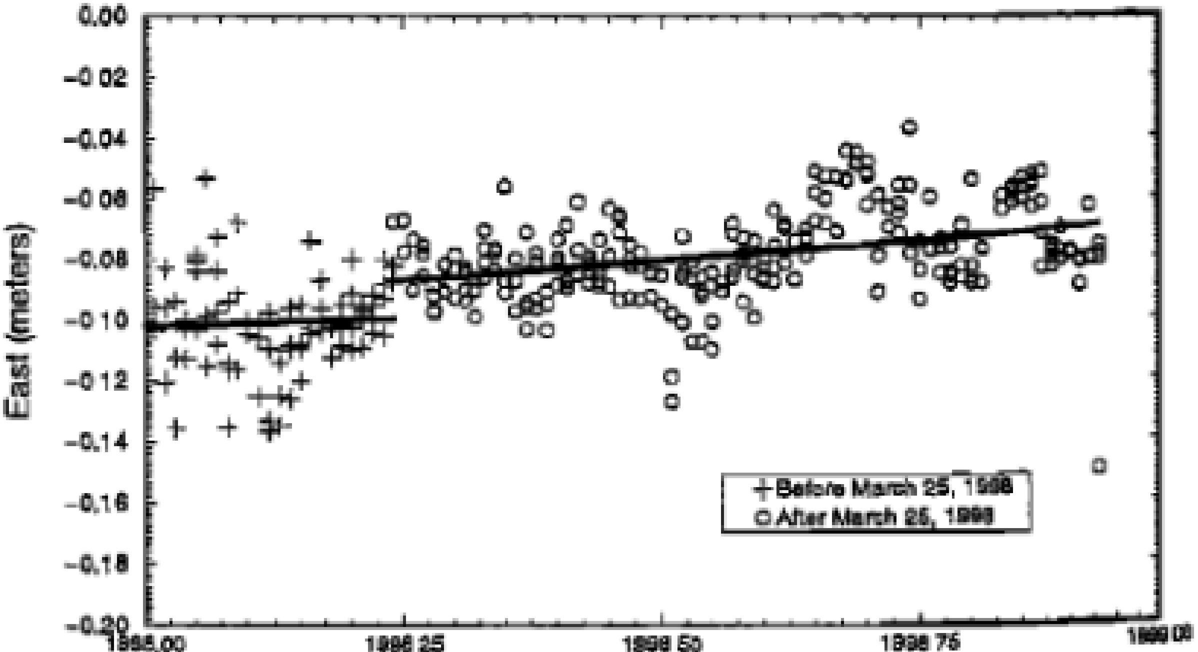


13±? mm
estimated



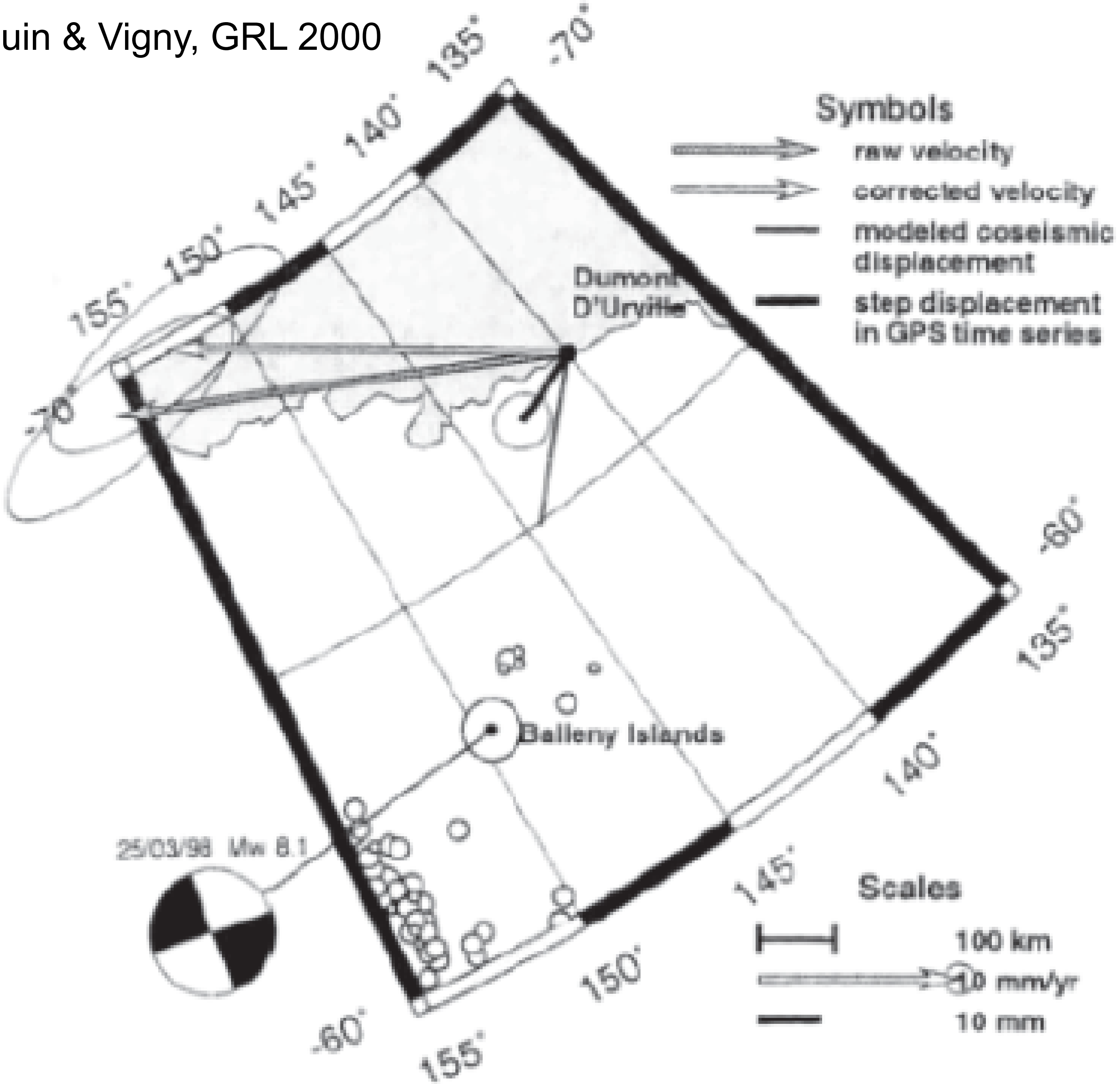
4±? mm
estimated

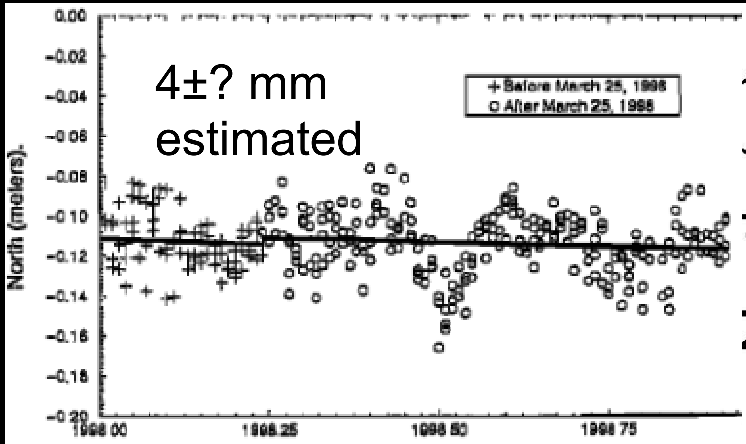
Bouin & Vigny, JGR 2000



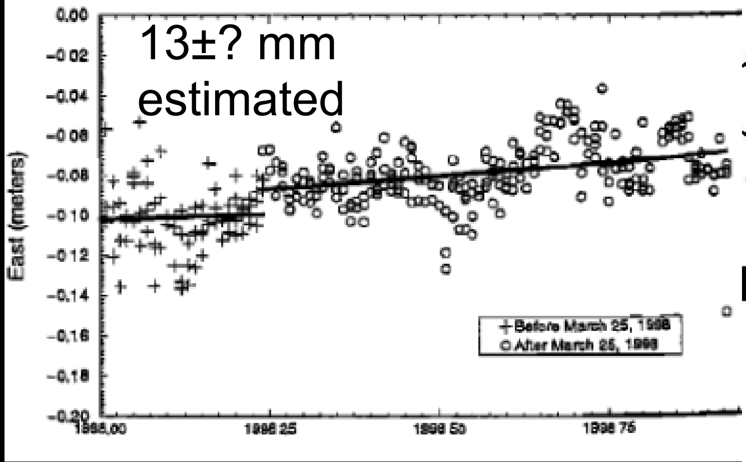
13±? mm
estimated

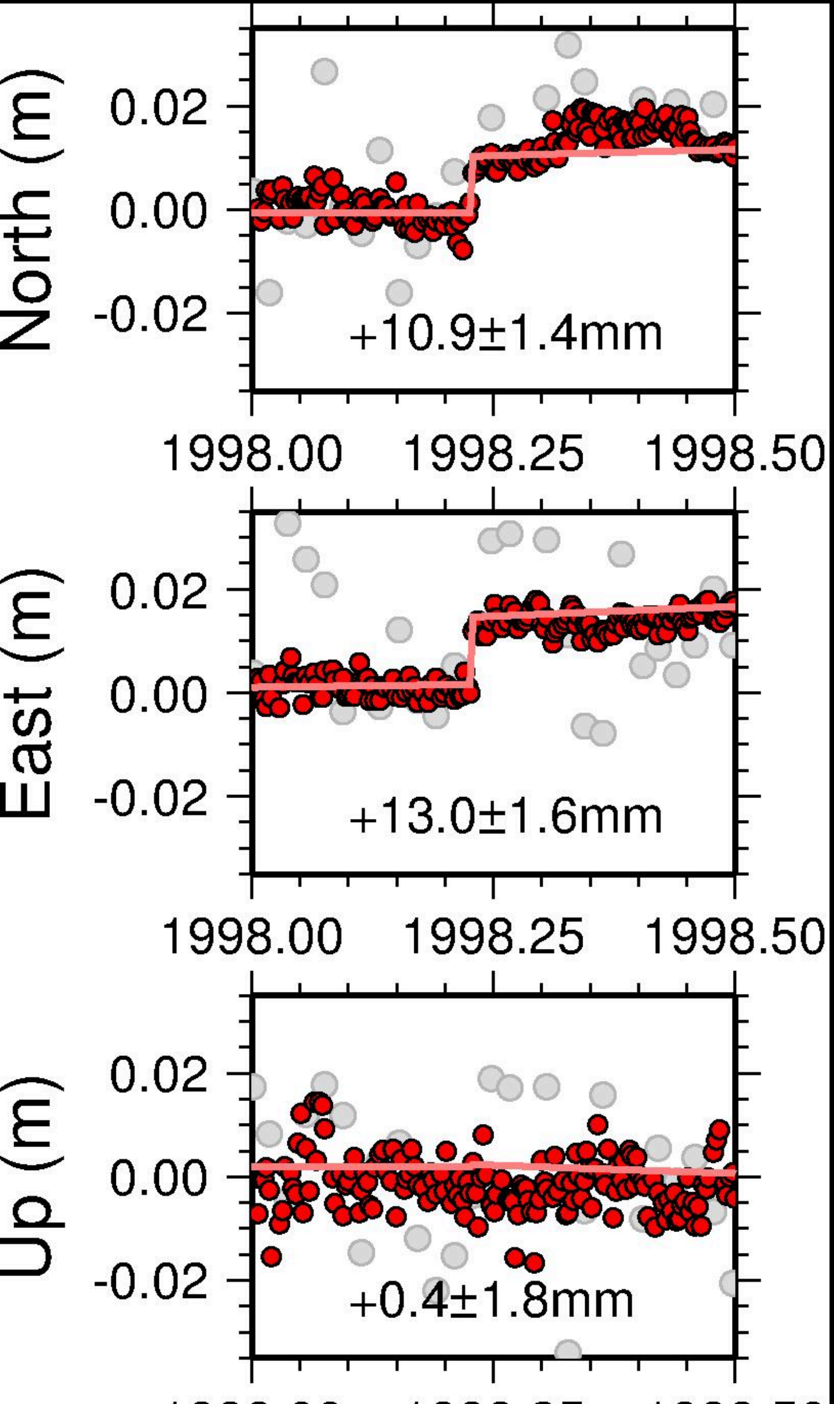
Bouin & Vigny, GRL 2000




4±? mm
estimated

Bouin & Vigny, JGR 2000


13±? mm
estimated


+10.9±1.4mm

+13.0±1.6mm

+0.4±1.8mm

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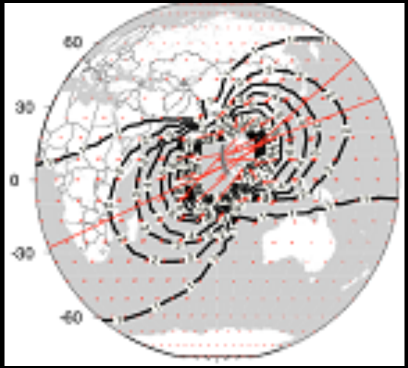
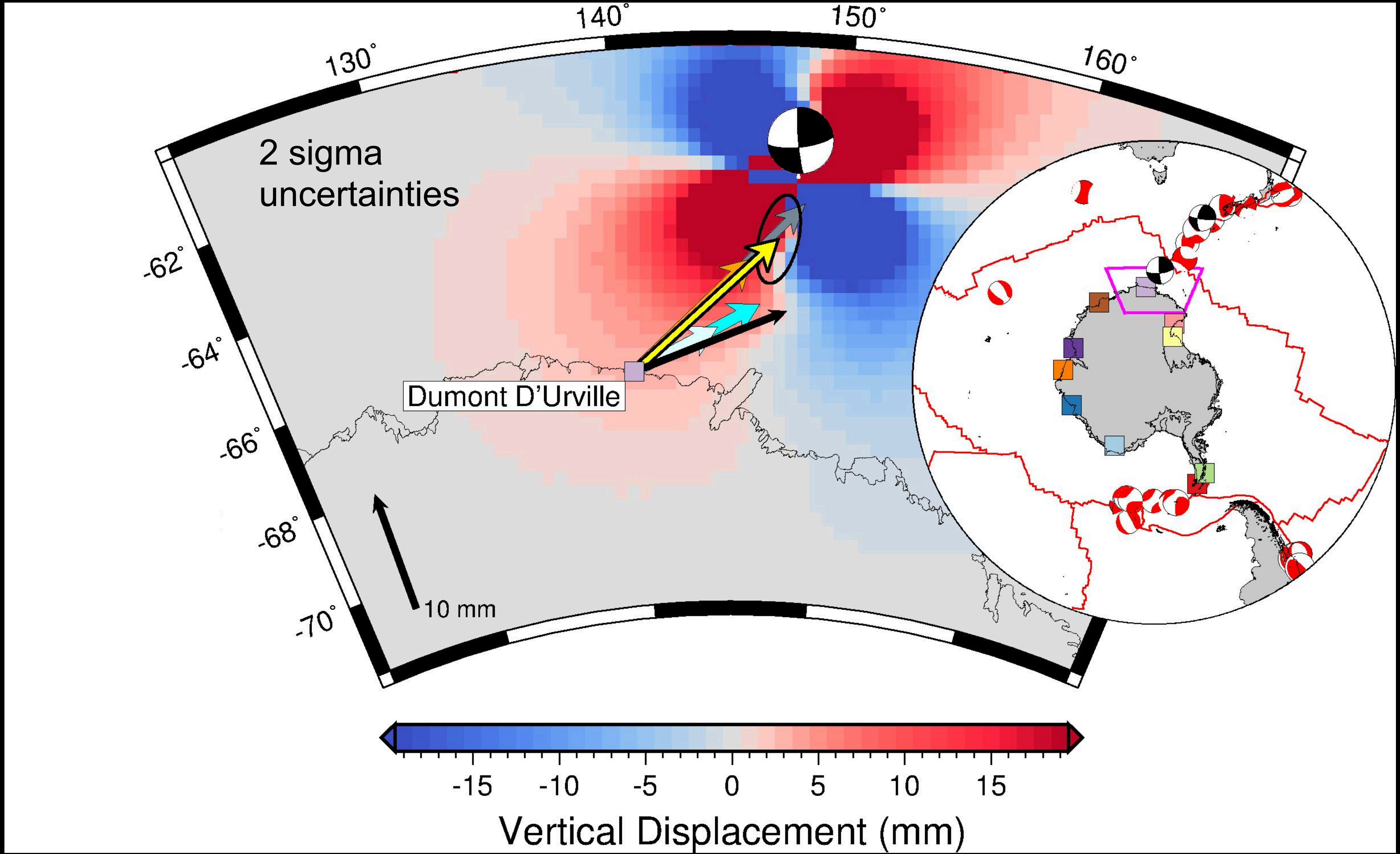
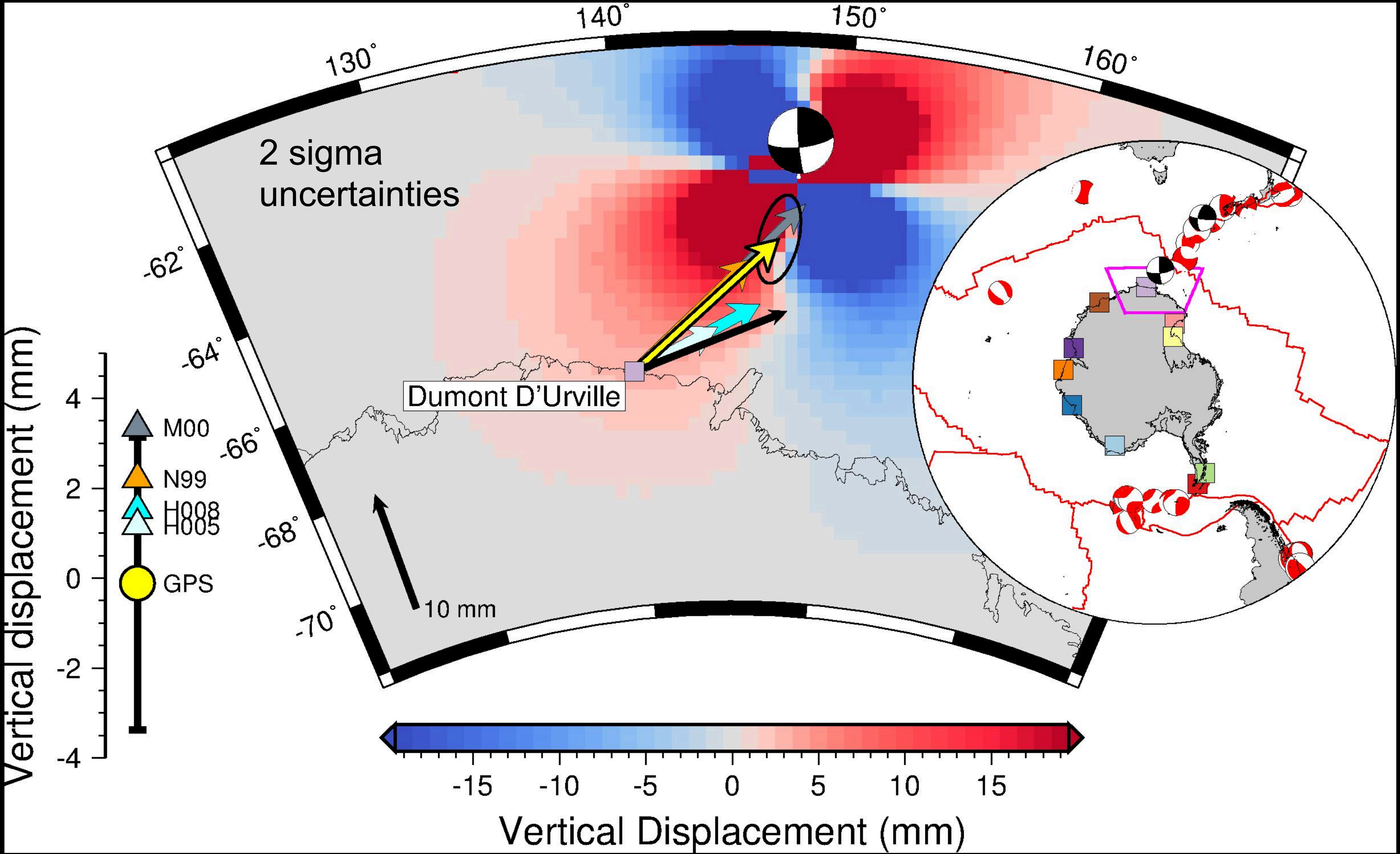
Model co-seismic displacement

- STATIC1D [Pollitz, 1996, 1997]
  - Spherical, layered 1D Earth
- Here, using PREM structure





GPS McGuire Nettles HenrySol8 HenrySol5



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GPS McGuire Nettles HenrySol8 HenrySol5

DORIS

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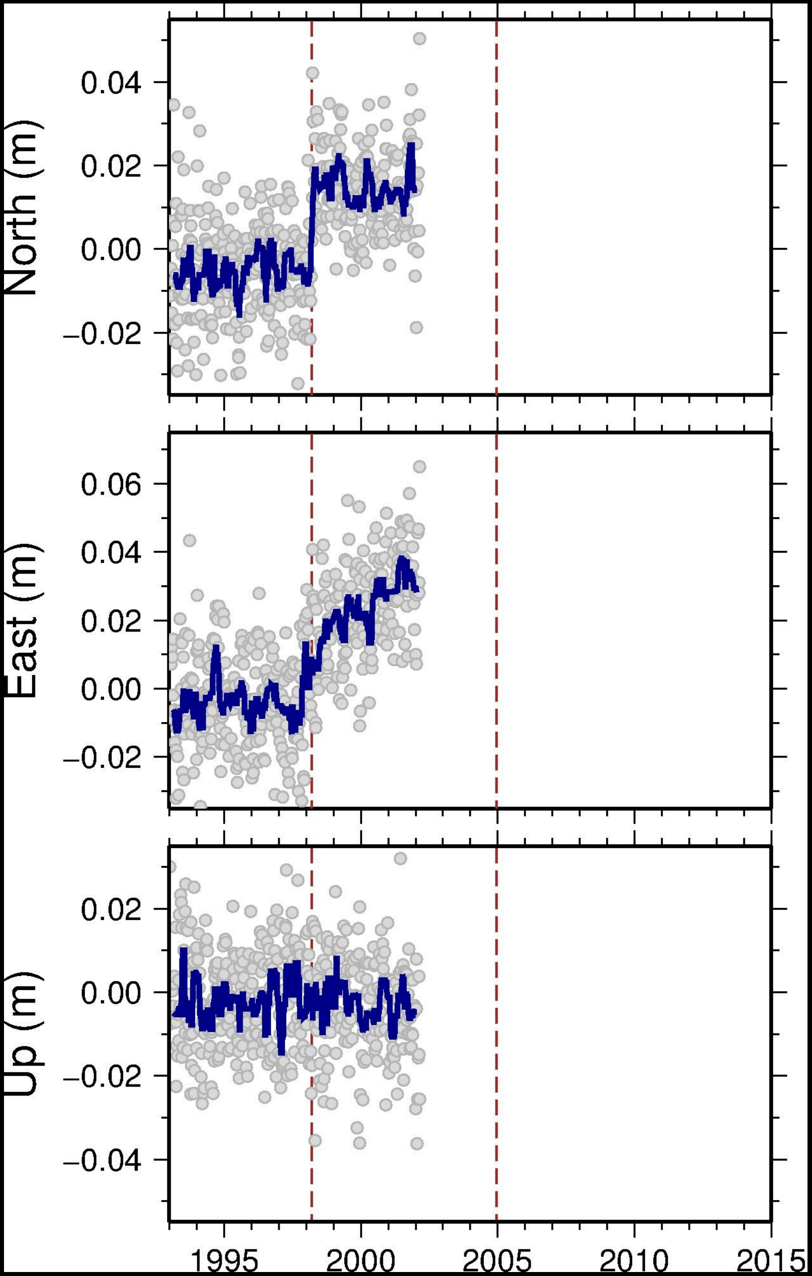
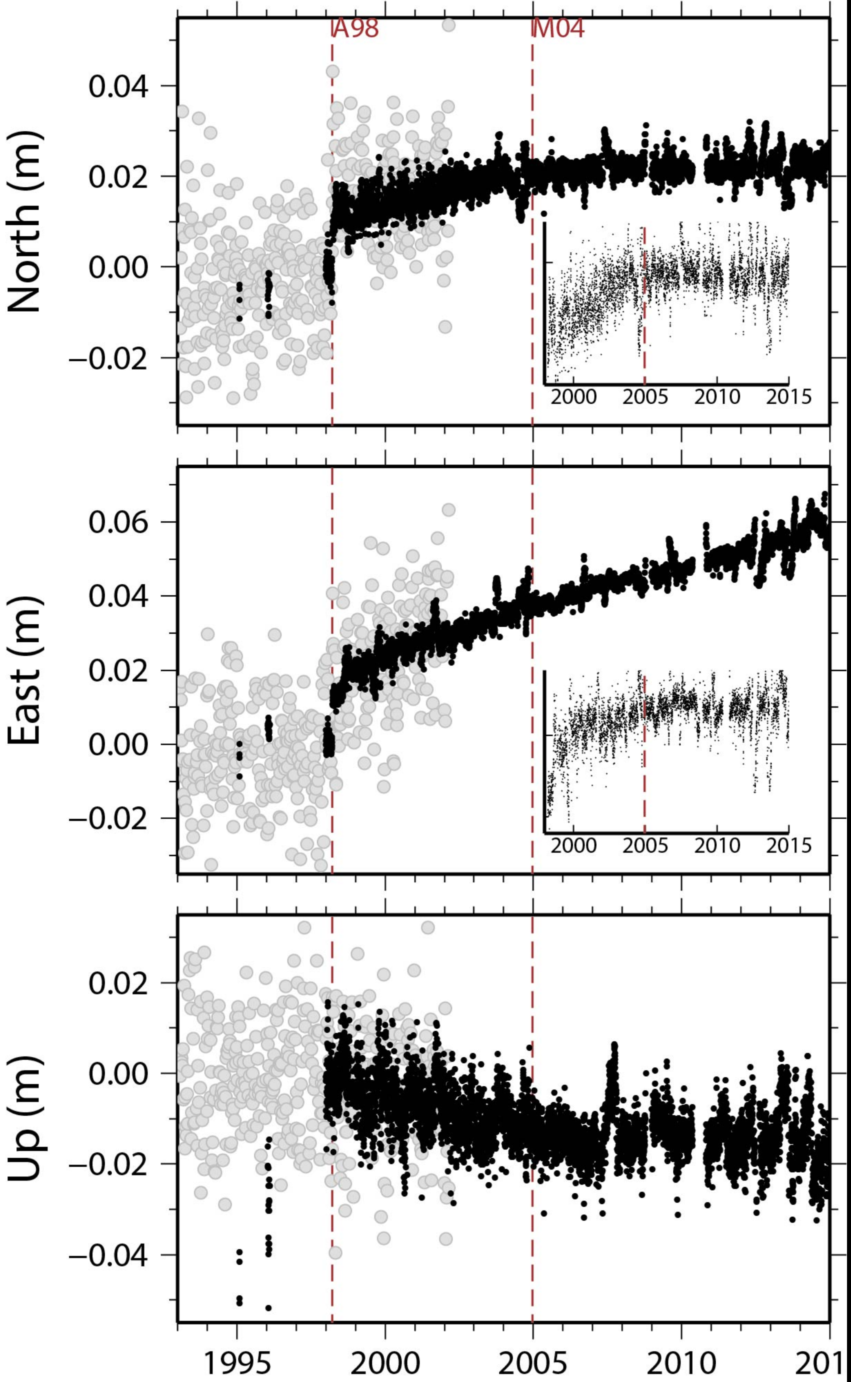
DORIS confirms GPS, evidence of post-seismic signal



IDS combined solution ids15wd09

1993-present, but station changes from 2002 – focus on first record only

Data plotted relative to pre-EQ DORIS velocity

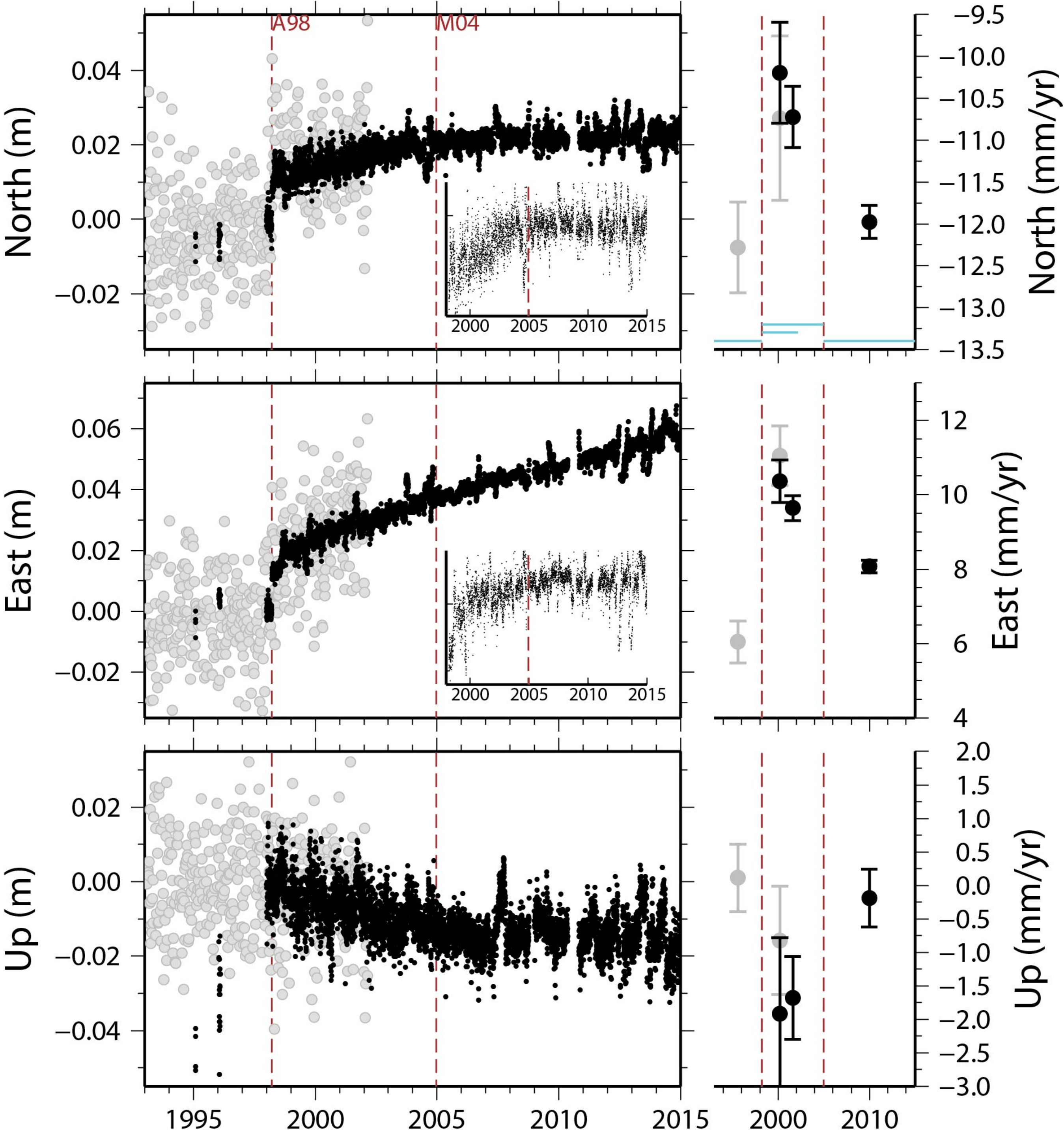


GPS analysis

- GIPSY 6.3
- JPL repro2 orbits+clocks
- VMF1
- 2nd order iono
- elev-dependent obs. Weighting
- our own fiducial-free to ITRF2008 transformation files

Uncertainties WN+FN (GPS) or WN (DORIS)

Data plotted relative to pre-EQ DORIS velocity


A98
M04
North (m)
East (m)
Up (m)
North (mm/yr)
East (mm/yr)
Up (mm/yr)
0.04
0.02
0.00
−0.02
0.06
−0.04
1995
2000
2005
2010
2015
−9.5
−10.0
−10.5
−11.0
−11.5
−12.0
−12.5
−13.0
−13.5
12
10
8
6
4
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0

The joy of fitting models to 1 data point

- Model viscous deformation using VISCO1D (Pollitz)
- 1d Spherical, layered Earth model with gravity

Elastic lithosphere [30..130km]

Low viscosity asthenosphere
Viscosity 10^{17} .. 10^{20} Pa s
Thickness 0..90km thick or fixed base at 220km

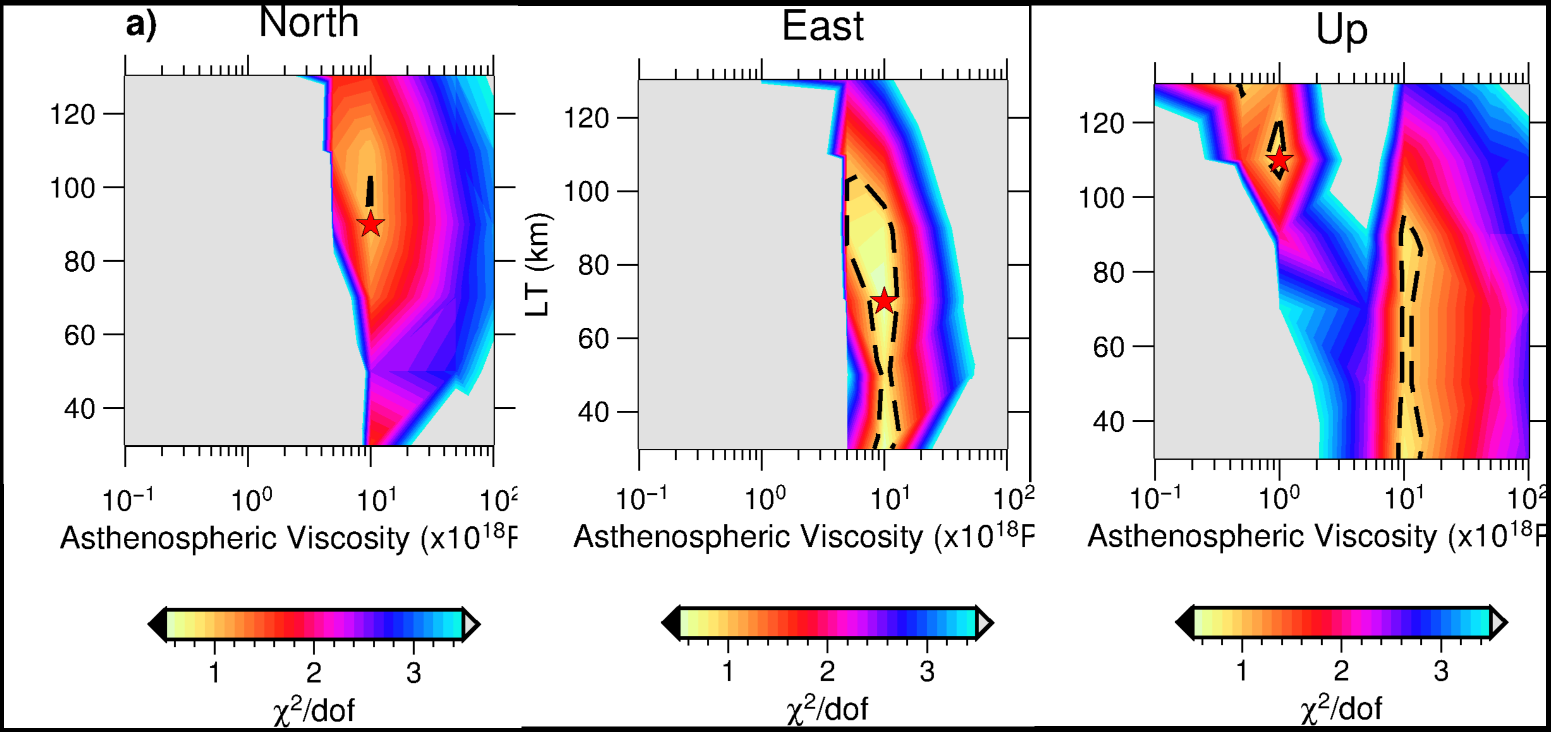
Upper mantle [10^{18} .. 10^{22} Pa s] to 670km

Both viscous layers – linear bi-viscous rheology – short term effective viscosity 10x lower

- Forced with McGuire et al rupture model with scaled moment to fit GPS co-seismic

Viscous modelling results [UM=10^{19} Pa s; Asthenosphere = 130km thick]

Difficult to fit all three components with a single model



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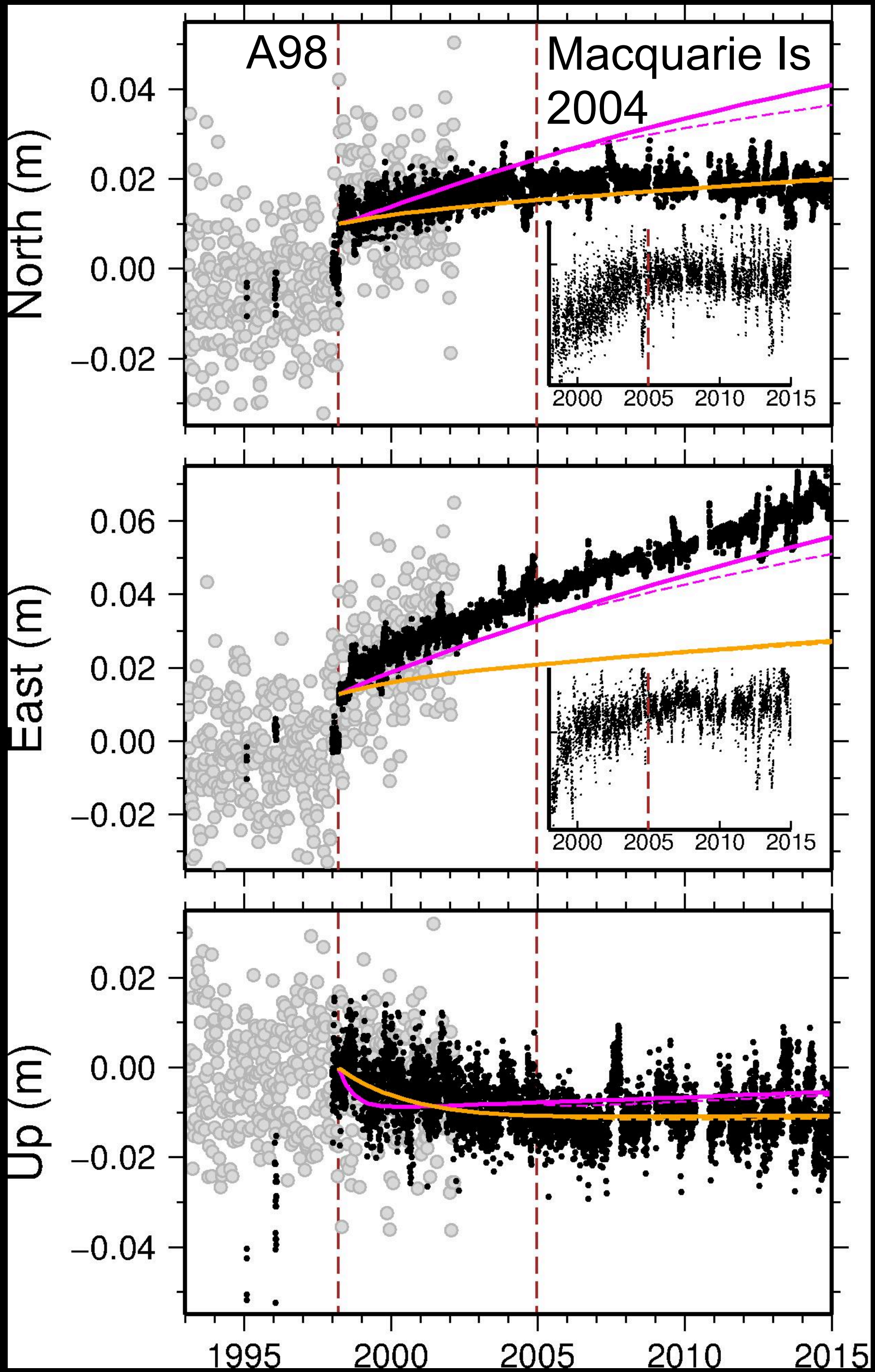
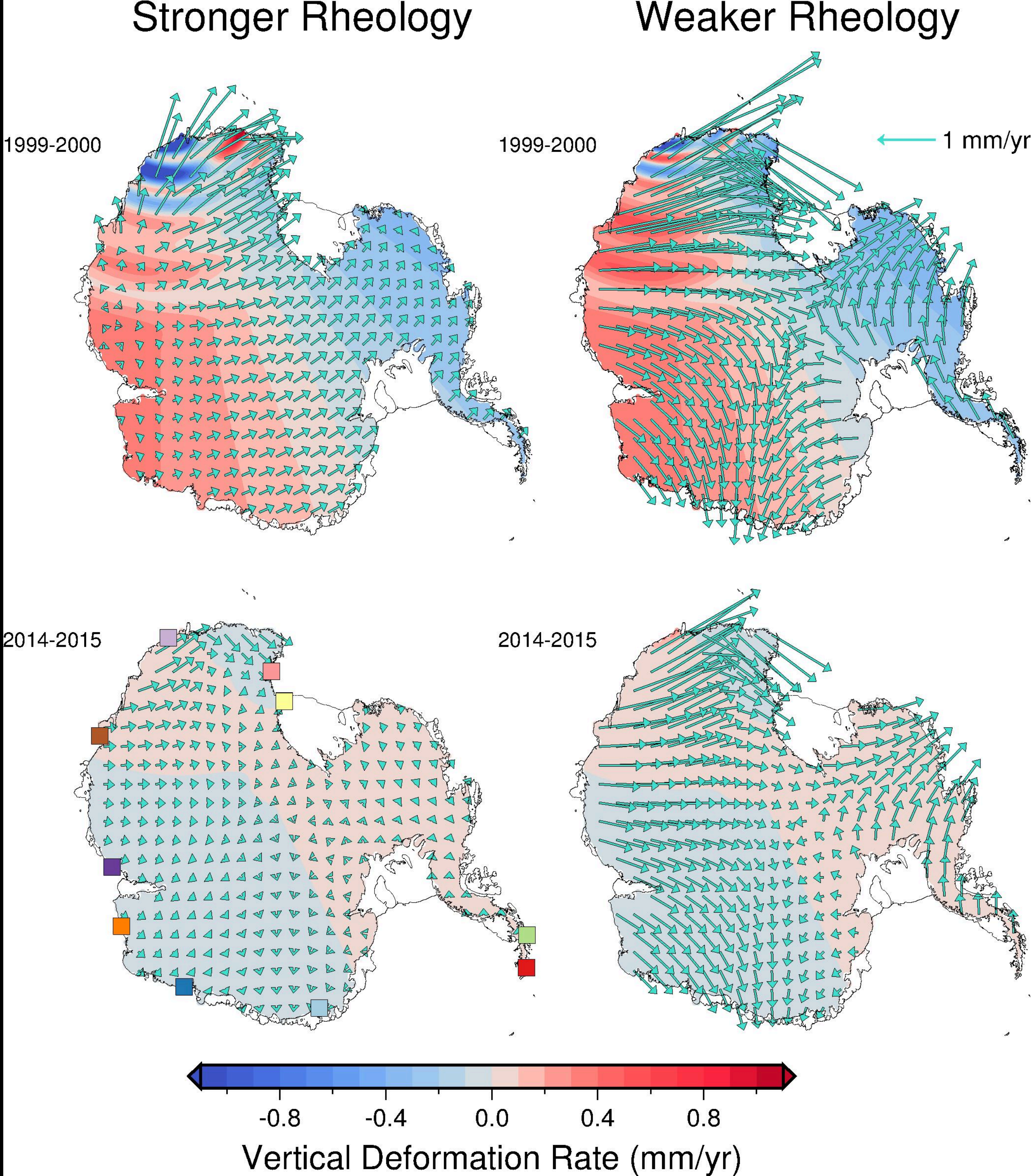
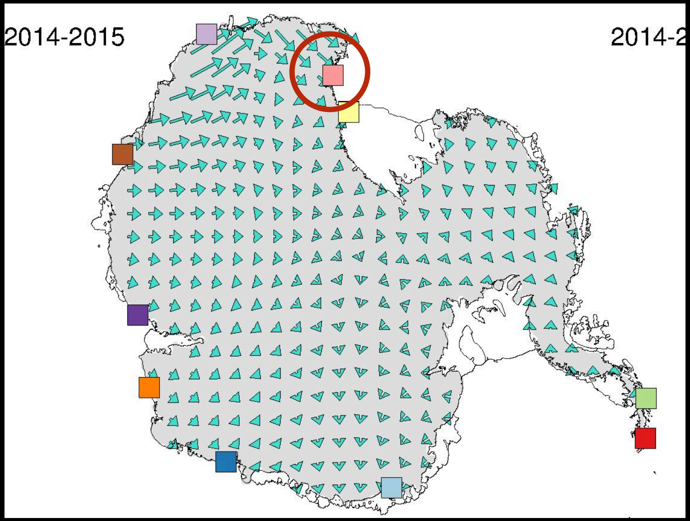


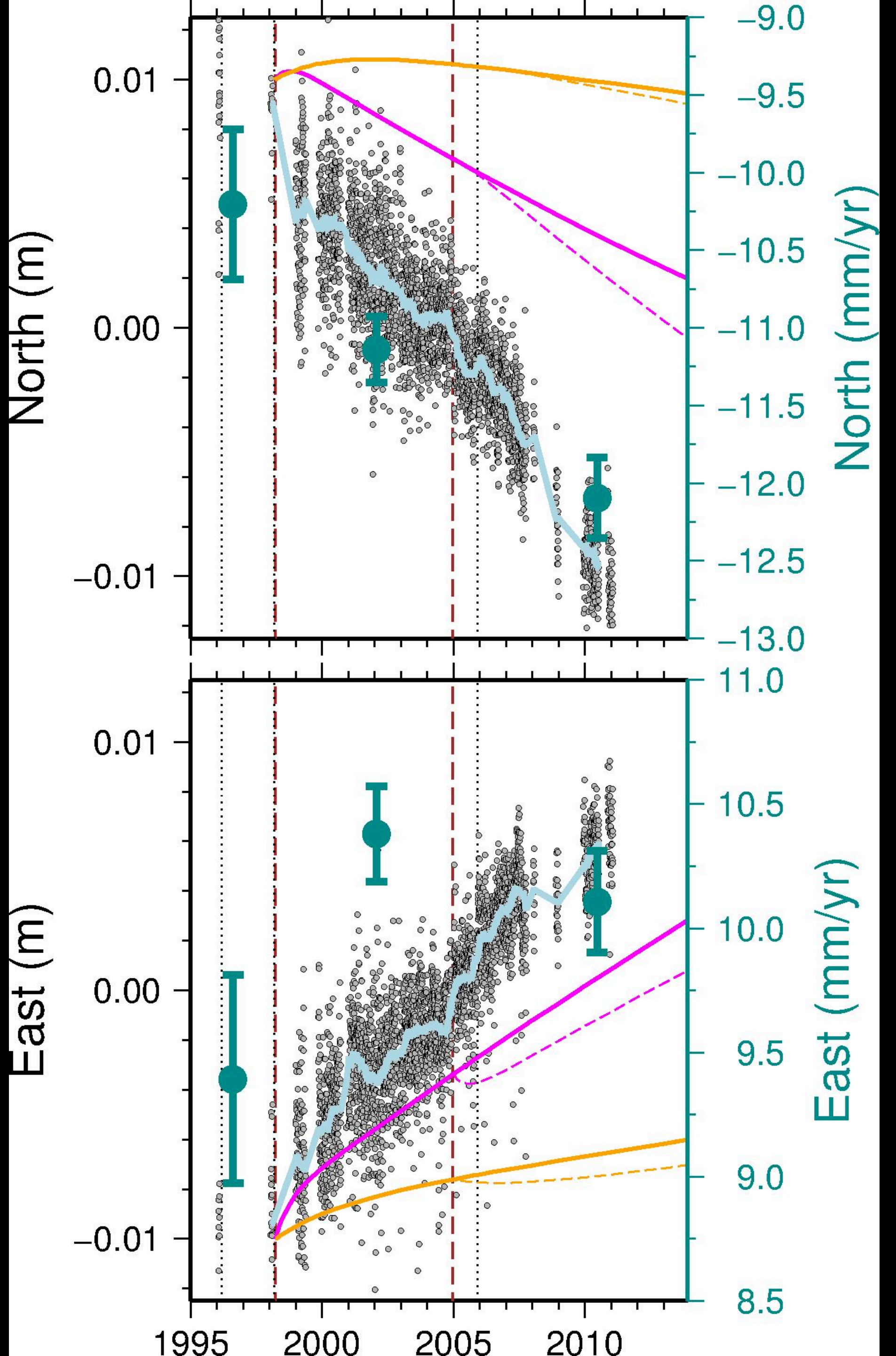
Asthenosphere and upper mantle viscosity of 6×10^{19} Pa s

Asthenosphere viscosity of 1.2×10^{19} Pa s and upper mantle viscosity of 1.4×10^{19} Pa s

Both have 90 km elastic lithosphere and 130 km thick asthenosphere


Stronger Rheology
Weaker Rheology
1999-2000
1999-2000
1 mm/yr
2014-2015
2014-2015
-0.8
-0.4
0.0
0.4
0.8
Vertical Deformation Rate (mm/yr)





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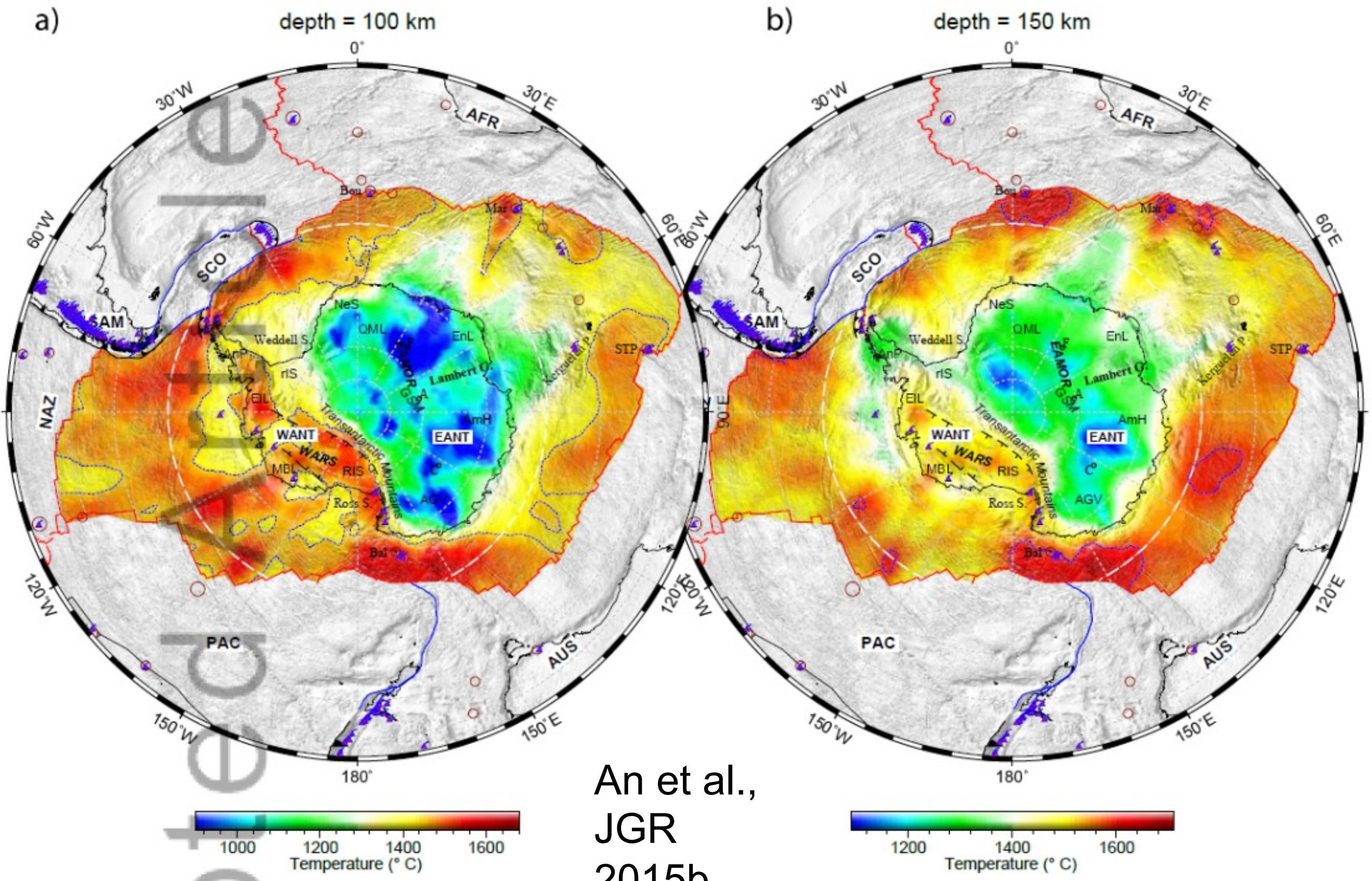
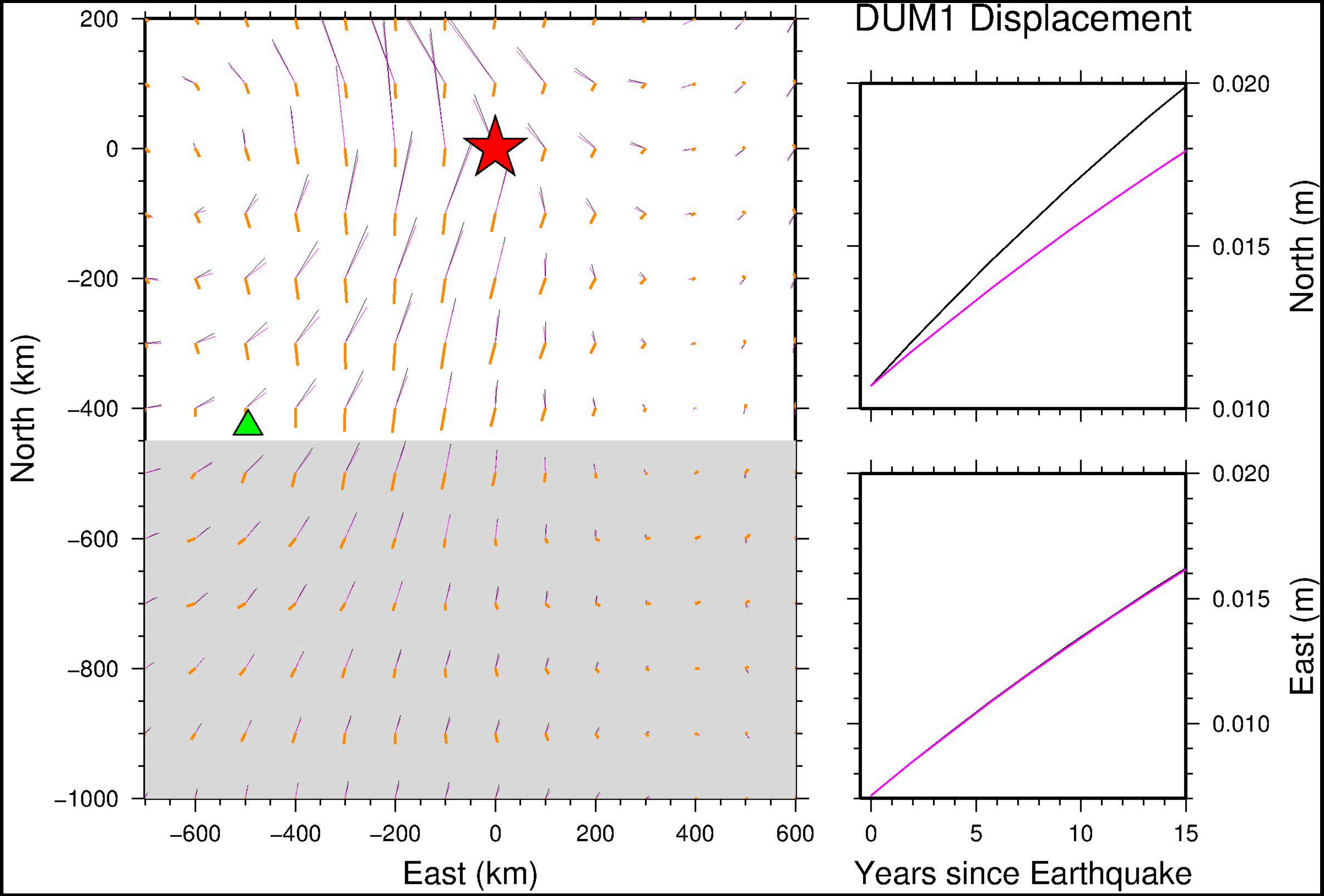
Lateral variation in Earth properties limits model realism



An et al., JGR 2015b



20% change in predicted northward motion

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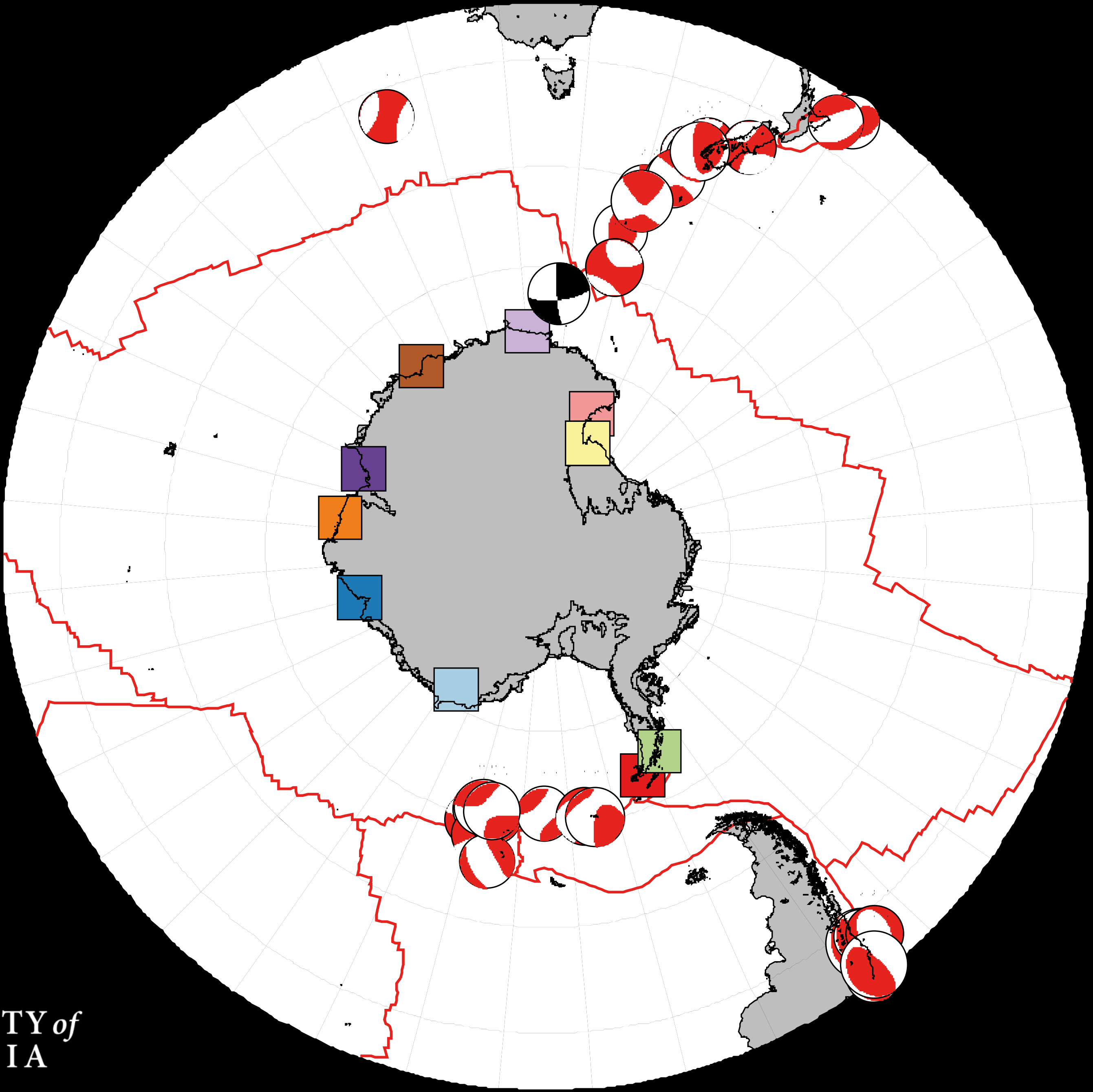

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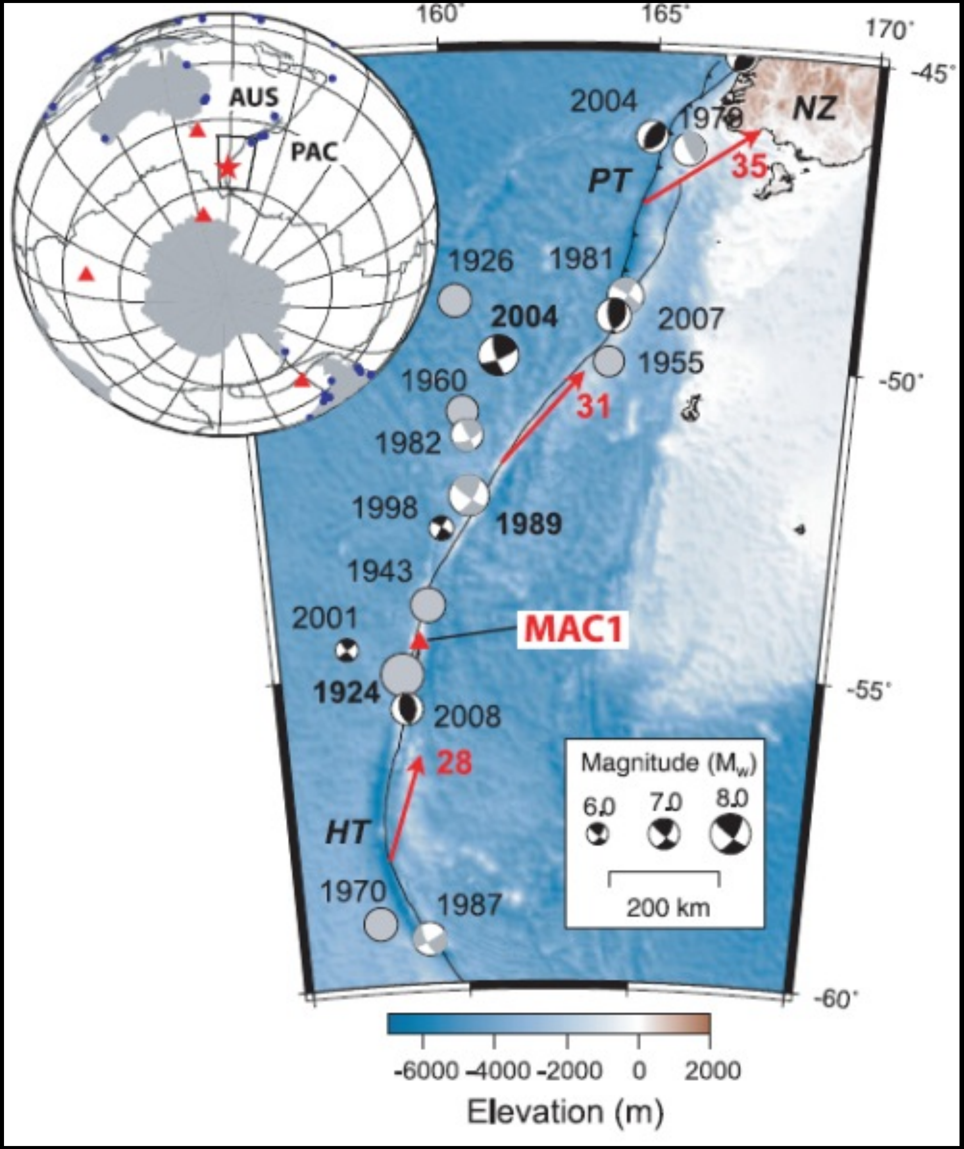
Conclusions

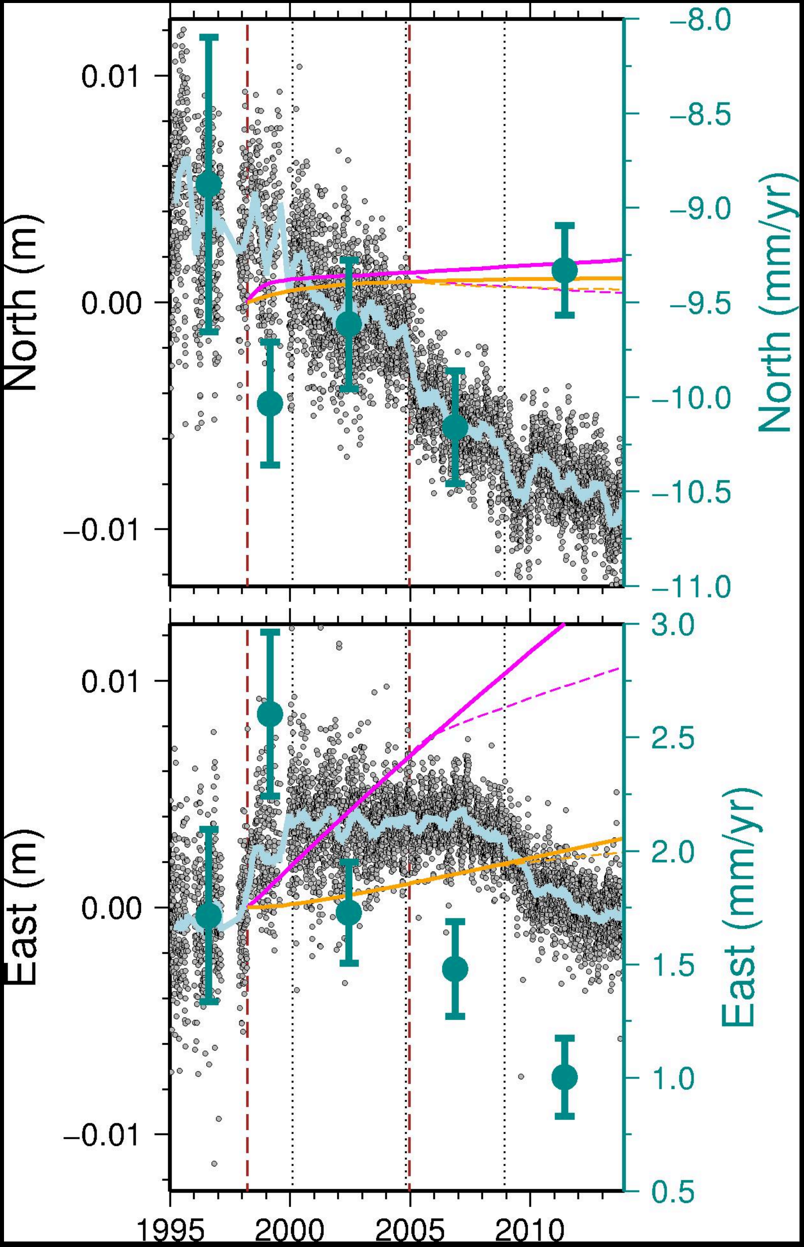
- Antarctica is not "stable" and has been deforming since the 1998 Antarctic Plate earthquake, and possibly also since the 2004 Macquarie Is EQ ~1800km away
  - The spatial extent is poorly known
- Cannot fit all three components of motion at Dumont D'Urville with a 1-d symmetric model with linear Burgers rheology
- Other large events since (and before) then, including off Antarctic Peninsula and in South America

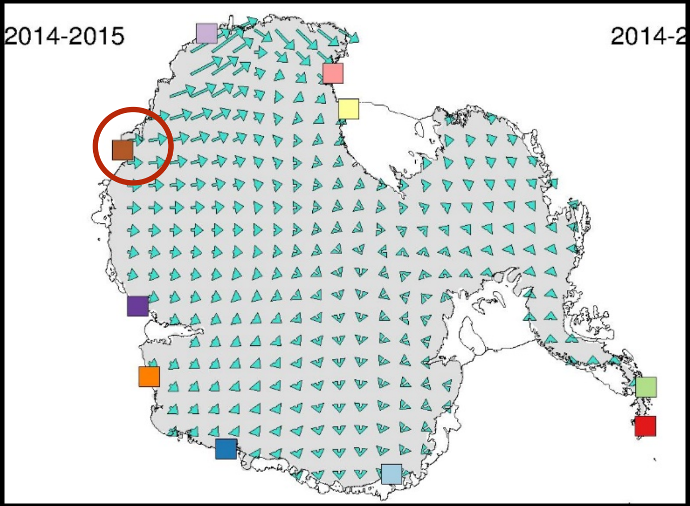
Discussion points

- Linear burgers rheology too simple
- Macquarie Is 2004 EQ



Watson et al GJI 2004





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Seismic models of rupture

Model	Depth (km)	Dip	Strike	Rake	Length (km)	Moment (Nm)
Henry Sol5	15	69	96	-18	320	1.37e21
Henry Sol8	15	69	96	-18	130	1.19e21
					60	0.6e21
Nettles	15	84	281	17	110	1.17e21
			271	17	50	0.58e21
McGuire	11	84	277	17	172	2.8e21